SLIP, TRIP, AND FALL INJURIES AMONG TRACTOR OPERATORS

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Mechanical Engineering

The University of Utah

May 2011

The University of Utah Graduate School

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ABSTRACT

Agriculture ranks among the most hazardous of occupations. It is second only to the mining and quarrying industrial sector. A large proportion of these injuries are associated with slips, trips, and falls among tractor operators while mounting/dismounting the tractors. This thesis is aimed at summarizing the results from a survey that was designed to investigate fall-related injuries and events and the compliance of late model tractors with published design recommendations for ingress/egress systems. An electronic survey, reviewed by the Institutional Review Board of University of Utah, was developed and administered to the tractor operators to investigate musculoskeletal pain, tractor usage patterns, tractor cab comfort and design, and to assess tractor ingress/egress systems to provide information in an effort to establish design guidelines for ingress/egress based on biomechanical and anthropometric considerations. The survey responses were all analyzed using the statistical software JMP 7. Additionally, a field study was conducted at two production sites in Idaho with 15 tractor operators and 5 different tractors. All the tractors were compared to SAE J-185 standards. Furthermore, 3D motion tracking of body movements during mounting/dismounting the tractor was recorded using ViconMotus™. General observations like the number of people facing the cab/facing away from the cab, maintaining 3-point contact while mounting/dismounting the cab are discussed.

To my beloved parents

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ACKNOWLEDGEMENTS

I would like to express my sincere thanks and appreciation to my advisor, Dr. Andrew Merryweather, for his patient guidance, advice, precious time, and constant support throughout my graduate career at the University of Utah, without which I would not have been able to complete my thesis successfully.

I would like to specially thank my other committee members, Dr. Donald Bloswick and Dr. Michael Blinn, for their helpful comments and suggestions for the betterment of my research.

I would also like to thank all the participants of the study for their cooperation and valuable feedback.

Finally, I would like to thank my family and friends, for their moral support and love throughout all my endeavors, which motivated me to further my education.

1 INTRODUCTION

1.1 Literature Review

Agriculture ranks among the most hazardous of occupations. Approximately 7,571 farmers and farm workers died from injuries sustained during farm work in the US between the years 1992 and 2005, which yields an average annual mortality rate of 26 deaths for 100,000 workers. The National Safety Council (NSC) estimated approximately 730 occupational fatalities in the agricultural sector in the United States in 2002 (a 2 percent increase compared to previous years). This yields an occupational mortality rate of 21 per 100,000 workers, which is second only to the mining and quarrying industrial sector that yields 29.1 deaths for 100,000 workers (Douphrate 2006). The agricultural industry had the third highest injury rate of all industries in 2002. Furthermore, data from NIOSH estimate that there was an average of 93,000 nonfatal OSHA recordable injuries on farms during the years 2001 and 2004 (NIOSH 2006). This estimate is likely under-representative of the actual number of injuries in this population. Among these injuries, falls continue to be one of the leading causes of nonfatal, serious workplace injuries (Jones and Switzer-Mclntyre 2003). A large proportion of these injuries are associated with mounting and dismounting machinery, including tractors. Tractors are associated with a large percentage of all fatal and nonfatal agricultural injuries (Bancej and Arbuckle 2000). According to data from the Bureau of Labor Statistics (BLS), 2,869 agricultural workers died from tractor-related accidents between 1992 and 2005. Results from a comprehensive analysis of Workers' Compensation Data among Colorado agricultural workers (23,484 agricultural-related injury claims) from 1992 to 2004 were reviewed and found 642 tractor-related injuries (Douphrate et al. 2009). A significant proportion of these claims (21 percent) were related to mounting and dismounting the tractor. Similarly, according to the Bureau of Motor Carrier Safety, Federal Highway Administration, in Washington D.C., in 1997, 54 percent of truck slip and fall accidents happen on the tractor and 46 percent on the trailer (Jones and Switzer-Mclntyre 2003). It appears that the mismatch between operators and machinery during mounting/dismounting constitutes an alarming safety concern. Table 1 summarizes the number of injuries related to mounting and dismounting tractors.

> "Coming home after plowing, when jumped out of the tractor to the hard concrete floor, the back got hurt!"(Timo Leskinen 2002)
>
> "Coming down from the tractor, the back was wrecked!"
>
> "Went out from the tractor and the knee cracked when climbing down!" (Timo Leskinen 2002)

These are the translations of original accident descriptions from the database of the Farmers' Social Insurance Institution given by the accident victims. Although these examples are not the most common or representative ones, they were chosen because of the damages caused to the skeletal system (Timo Leskinen 2002). Apart from accidents, musculoskeletal (micro) trauma could also be expected because of shocks when landing after jumping off the tractor. Also, frequent mounting and dismounting of the tractor may cause tiredness and strain injuries.

Table 1: Contributing factors of tractor-related injury claims among Colorado agricultural workers (Douphrate et al. 2009)

Worker Action	N	%
Dismounting Tractor	101	15.7
Mounting Tractor	29	4.5
Repeated Mounting/Dismounting	5	0.8
Total	135	21

In Australia, the agricultural sector has the second highest number of work-related deaths. Of these, tractors account for 15 percent of work-related fatalities, which yields an average mortality rate of 22 deaths per year (Day 2005).

The purpose of this thesis is to summarize the results from a survey that was designed to investigate fall-related injuries and events and the compliance of late model tractors with published design recommendations for ingress/egress systems. We also conducted a field study to define the kinematics and kinetics of mounting and dismounting different tractor models at two production sites in Idaho.

1.2 Objective

A survey was developed to investigate musculoskeletal pain, tractor usage patterns, tractor cab comfort and design, and to assess tractor ingress/egress systems to provide information in an effort to establish design guidelines for ingress/egress based on biomechanical and anthropometric considerations. The main objective of the field study was to evaluate whole body biomechanics during mounting and dismounting tractors to determine the factors that potentially lead to instability and may contribute to fall-related injuries among agricultural tractor operators. Data were collected regarding physical factors and tractor ingress/egress systems and the influence of environmental factors that were reported to have contributed to mounting or dismounting falls. An investigation of current design specifications for commercial agricultural equipment was carried out and compared to commonly found tractor designs to determine their level of compliance. Finally, tractor design modifications and retrofits were considered that could act as interventions to provide better access to tractor cabs and reduce the number of injuries related to mounting and dismounting.

1.3 Factors Influencing Fall Risk from Tractors

It has been found that the access path of a tractor cab is very rarely used properly, i.e. only in 6 percent of the egresses. There are many factors that influence the fall risk from tractors, including physical and environmental factors.

1.3.1 Physical Factors

Tractor design includes steps, cab configuration, and placement and availability of handrails. Common factors could be shortcuts in the use of steps and handrails, jumping from steps or stepping down with a twisted back. Also, the usability of the ingress/egress systems, the variability of human action (between and among users), and the interaction between the two may have a role in sequences leading to accidents. We performed an investigation to evaluate how each of these tractor components may contribute to the posture and technique selected by experienced tractor operators while mounting and dismounting.

1.3.2 Environmental Factors

There has been some descriptive research into relationships between environmental factors such as poor lighting, wind, rain, snow, ice, dirt, grease, diesel spills, and a combination of factors. Douphrate et al. (2009) found 5.2 percent of injuries related to weather. The presence of foreign contaminants (water, mud, ice, and snow) will be considered when assessing ingress/egress systems for tractors and slip/fall potential.

Slips and falls are often interactions between multiple factors including physical and environmental conditions. When these intrinsic and extrinsic factors are well balanced, the slip potential is low. Environmental factors are likely to contribute to a slip or fall, but age also appears to play a significant role in slips and falls.

Slip/Fall normally results when:

1. Forces at the interface between the body and the system are greater than either the maximum forces generated by the body (grip strength) of maximum forces based on physics.
2. Forces at body articulations are greater than maximum reactive forces.
3. Contact between body and system is not ideal.

1.4 Tractor Standards

SAE J-185 is a major standard used in the design of safe vehicle and equipment access systems. It was first published in 1972 under the title "Access Systems for Construction and Industrial Equipment." This landmark publication formulated basic requirements for the design of adequate handholds and footholds for climbing irregular vertical surfaces such as those encountered when climbing to the operator's cab on various construction and industrial vehicles. This publication was revised in 1981, 1985, and again in 1988 with improved precision and minimal changes to it (Nelson and Associates).

1.4.1 Select Requirements of SAE J-185(1970)

Section 4.7 of SAE J-185(1970) states: Steps, ladders and grab rails to, on, and from platforms and walkways should be designed to invite the person using them to have three limbs on the system at all times (two hands and one foot; or two feet and one hand).

Section 5.1 of SAE J-185(1970) states: The maximum height of the first step from ground to the machine should not exceed 30 inches when the machine is in the normal parked position. The preferred height of this step is 16 inches.

Section 5.2 of SAE J-185(1970) states: The maximum distance between steps of vertical ladders on machines is 16 inches. The preferred distance between steps is 12 inches.

Section 5.6 of SAE J-185(1970) states: The minimum toe clearance from the outside edge of the step should be 5 inches. The preferred distance is 7 inches.

Section 5.11 of SAE J-185(1970) states: The design of steps should minimize the accumulation of debris. The tread surface should be a high slip resistant surface and should aid in the cleaning of mud and debris from the shoe sole.

Section 6.1 of SAE J-185(1970) states: Grab rails, appropriately spaced to provide continuous support to moving man, should be placed within convenient reach.

Section 6.2 of SAE J-185(1970) states: The preferred cross section of a grab rail and grab iron is circular. A square or a rectangular cross section with round corners is permissible.

Section 6.3 of SAE J-185(1970) states: For circular cross section grab rails and grab irons, the maximum diameter should be 1-1/2 inches. The minimum diameter should be ¾ inches. The preferred dimension is 1 inch. For square or rectangular cross sections, these dimensions apply across flats.

Section 6.6 of SAE J-185(1970) states: Grab rails and successive grab irons should be placed parallel to the path of motion of the user. Grab irons may be oriented vertically or horizontally but should be consistent with a given system.

Section 6.10 of SAE J-185(1970) states: On incline ladders, where hip clearance is a factor, the preferred spacing between parallel grab rails is 24 inches.

Section 6.11 of SAE J-185(1970) states: The preferred grab rail height vertically above any step or incline ladder is 36 inches.

Table 2 describes some generally accepted design criteria among various standards for commercial vehicles.

Table 2: Generally accepted design criteria

Standard	1st Step Height	Step Spacing	Step		
			Depth	Width	Surface
Liberty Mutual	18"-23"	6"-10"	4"	6"-19"	Antislip
SAE J-185	16" Pref;30" Max	12" Pref;16"Max	5"	6"-12"	Slip Resist
RCCC RP404	24" Pref;27" Max	Depends on step offset	6"	6"-12"	Safety Material
MIL STD 13207D	16"-23"	10"-16"	7.5"	7.5"-15"	Serrated Grating

1.5 Common Reasons for Falls

Many agricultural workers have suffered wrist, arm, hip, leg, and ankle injuries as a result of falling from their tractors. A traumatic injury from a fall could result in many lost workdays and even death. In spite of awareness of this problem by many safety professionals for many years, poor access/exit systems are still found today, and the accidents due to slips and falls are still occurring at an alarming rate. Based on a thorough review and analysis of the tractor models in use today, the following were found to be the most common and major reasons for slips and falls among tractor operators (Hurst 1983):

1. Hidden steps not permitting visual contact by operator
2. Lack of uniformity in design of steps and vehicles
3. Excessive height of step raisers
4. Lack of or poorly placed side steps
5. Lack of or mislocation of handrails
6. Other miscellaneous design problems
7. Poor tread surface conditions
8. Presence of environmental factors (rain, mud, snow, ice)

2 METHODS

A unique two-step methodology has been devised to meet the objectives of this study.

Step 1: Initially, an electronic survey has been developed to assess the tractor ingress/egress systems and posted on various agricultural related websites, forums, and blogs. The basic goal was for the survey to be available to as many tractor users as possible throughout the nation. Depending on the responses from various tractor users from around the USA, design guidelines have been developed for ingress/egress systems based on biomechanical and anthropometric considerations. These data were analyzed using statistical methods such as Analysis of Variance (ANOVA), Tukey-Kramer HSD test, F-test, and t-test.

Step 2: In addition to the survey, a field study at two production sites in a rural farming community in Idaho with 15 experienced male tractor operators was conducted to investigate the biomechanics of mounting and dismounting 5 tractor models. They were required to complete a consent document and be free from physical conditions that may contribute to increased risk of falls. The study was approved by the University of Utah's Institutional Review Board (IRB). The chosen participants were between the ages of 18 and 69. Hence, the inclusion of some older adults was thought of as being important for obtaining accurate results.

3 ELECTRONIC SURVEY ANALYSIS

3.1 Methodology in Detail

An electronic survey, which was developed using FileMaker Pro version 9, was taken by 36 tractor operators. The survey consisted of 30 different questions about various biomechanical aspects of tractor ingress/egress systems as well as important descriptive characteristics and human factors. The questions were approved by the Institutional Review Board (IRB), a committee that has been formally designated to approve, monitor, and review biomedical and behavioral research involving humans, with the aim to protect the rights and welfare of the research subjects. The questionnaire is attached in Appendix A.

3.2 Survey Validation and Its Importance

The American Educational Research Association defines validity as “the degree to which evidence and theory support the interpretations of test scores entailed by the proposed use of tests. Validity is therefore the most fundamental consideration in developing and evaluating the tests.” Post-hoc validation of our electronic survey has been conducted to confirm the conclusions from our results.

Initially, even before the survey was administered to the sample population, care was taken so that all the questions in the survey have been phrased precisely and succinctly, using as simple language as possible. The questions were developed with a positive stance in order to avoid drowning out the content. The questions were framed in such a manner that no question was found to be of an offensive nature to the survey respondents. The whole layout of the survey was designed in such a way that it could be easily understood. Moreover, sufficient care has been taken to avoid usage of any jargon in the questions asked, in order for all the users to understand the questions clearly. Also, the background questions or the demographic questions that include the age, gender, height, weight, and amount of experience with the tractors were covered to verify the background of the survey takers. Extra measures were taken to avoid any sensitive questions that may offend the user. Furthermore, open- and close-ended questions have been used wherever appropriate. The open-ended questions were used where the users might feel it necessary to suggest any recommendations they had in the design of the tractors. Additionally, there were also some questions which were of close-ended nature. These questions provide a means for coding responses or assigning a numeric value and statistically analyzing the data (Creswell 2005). Single-select questions were asked where it was necessary for the users to choose only one of the responses provided. Similarly, multiple-select questions were also asked where there could be a possibility of having more than one choice for the question asked. For example, when the survey takers were asked to choose the body parts where they experienced pain, it was designed in such a way that the users could select more than one answer. In addition, care was taken to avoid any presence of overlapping responses, which may lead to confusion when answering a question, by creating distinct options. Further, any mismatch between the question and the available answers has been avoided.

Secondly, after completion of the survey design, it was administered to some experienced tractor users for pilot testing. This helped determine that the individuals in the sample are capable of completing the survey and that they can understand the questions. The users were asked to suggest any changes or modifications for the betterment of the survey. Finally, the survey has been modified and redesigned through multiple iterations to reflect their concerns. Only after this validation process, the survey was posted on different websites and forums and sent to tractor users for participation.

3.3 Results

3.3.1 Demographics

The data collected from the survey have been analyzed and the corresponding demographics have been determined from the sample of tractor operators who had participated in the survey at the time of analysis. The tractor models John Deere and Case were the most common tractor models that the operators used every day. The average age was 34.1 years, with a Standard Deviation (SD) of 12.5. The average weight was 208.1lbs with a SD of 47.3. On average, the tractor operators had 22 years of experience working with the tractors (with a SD of 13.7) and, 21.9 years of operating the tractors (with a SD of 13.9). The average amount of time spent on a tractor everyday was 7 hours (with SD of 3.9) Moreover, the average amount of time spent operating the tractor before taking a break was 4.9 hours (with SD of 3.0).

Apart from the demographics, the data compiled from the survey were analyzed using JMP 7.0, developed by the SAS Institute, to understand the responses from the sample of tractor operators who took the survey. According to the analysis that was carried out, the most popular tractors used by our study participants were John Deere, followed by Case and Massey Ferguson. The frequency distribution of the tractors is shown in Figure 1. It was determined that nearly 86.1 percent of operators complained about experiencing pain or discomfort while operating the tractor. The survey was designed in such a way that the operators were required to rate the pain levels for all parts of the body, on a scale of 0 to 10, 0 being no pain and 10 being the worst pain imaginable. About 77.8 percent of the operators admit that they experience severe pain in the Lower Back area. The body region with the second highest report of pain was the Neck, with 41.7 percent of operators reporting neck pain. Figure 2 shows the percentage of operators reporting pain from the electronic questionnaire. Also, the minimum, maximum, and average pain rating of each body part has been recorded in Table 3. Furthermore, a layout of the design of the question where the survey takers were supposed to give the pain ratings to different body parts is shown in Figure 3.

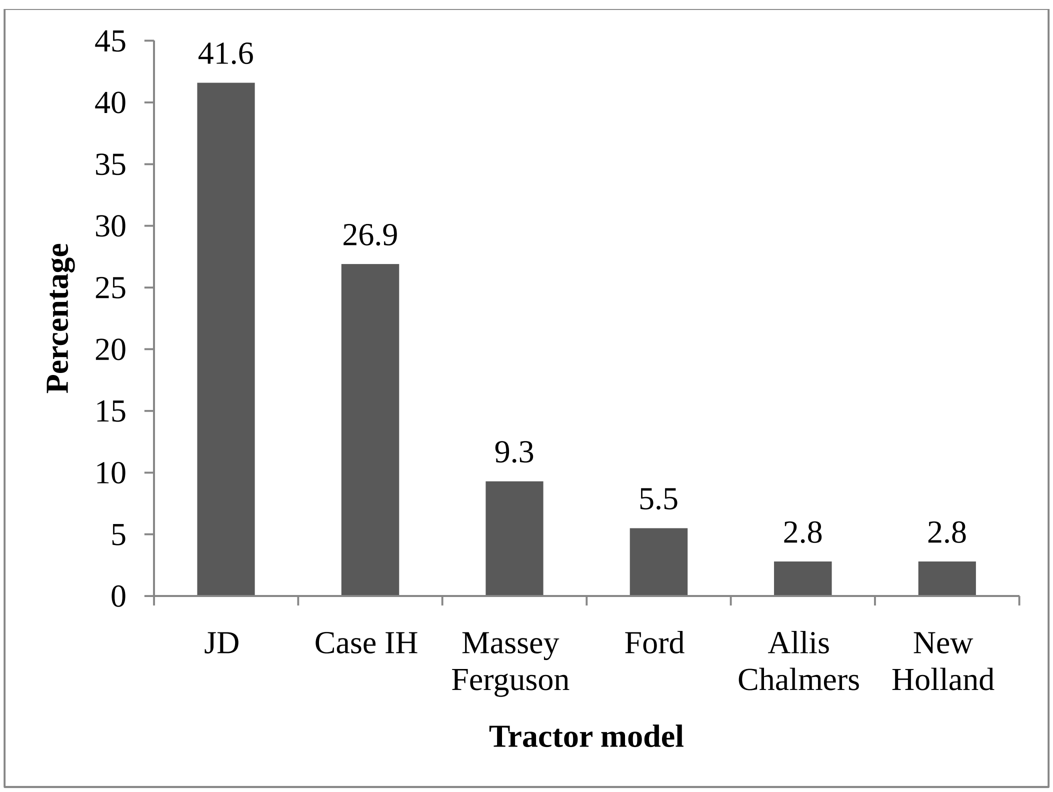


Figure 1: Frequency distribution of tractor models

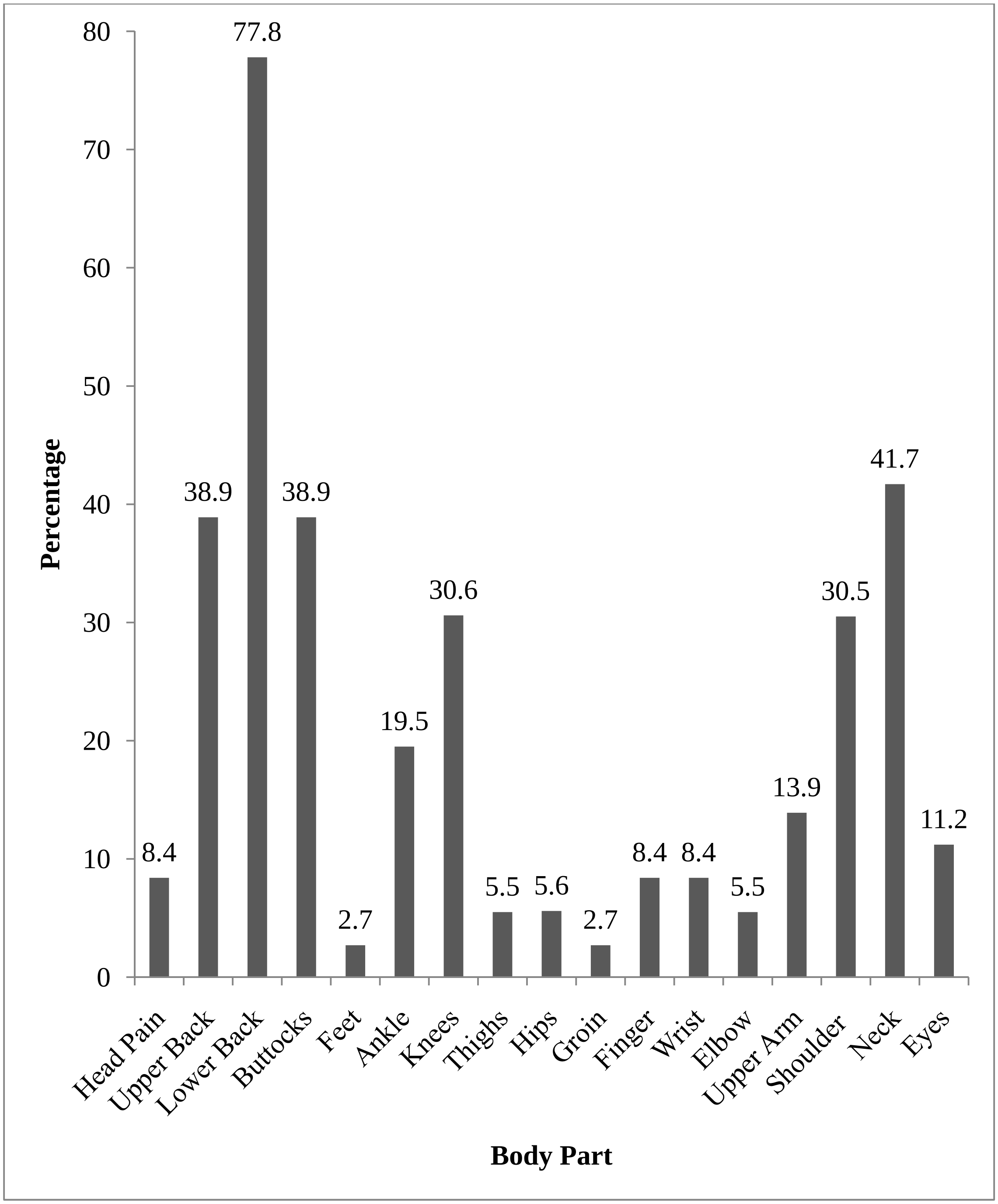


Figure 2: Percentage of operators reporting pain by body region/part

Table 3: Pain ratings

	N	Minimum	Maximum	Mean	Standard Deviation
Ankle Pain	31	0	2	0.2	0.5
Knee Pain	31	0	6	1.3	1.9
Thigh Pain	30	0	6	0.3	1.1
Hip Pain	30	0	6	0.2	1
Groin Pain	31	0	0	0	0
Finger Pain	31	0	1	0.06	0.2
Wrist Pain	31	0	3	0.1	0.5
Elbow Pain	31	0	3	0.2	0.7
Upper Arm Pain	31	0	5	0.5	1.3
Shoulder Pain	31	0	8	1.8	2.4
Neck Pain	31	0	8	2.5	2.9
Eyes Pain	31	0	7	0.5	1.4
Head Pain	31	0	8	0.6	1.9
Upper Back Pain	31	0	8	1.7	2.4
Low back Pain	31	0	8	4.6	2.1
Buttock Pain	31	0	7	1.7	2.2
Feet Pain	31	0	0	0	0

Also, the users were asked if the inflicted pain had any effect on their work. Even though the pain does not prevent the operators from working, about 37.5 percent of the sample concedes that it slows down their work. About 29 percent say that the pain does not affect work, while 16.7 percent agree that they have little pain. Figure 4 shows the severity of the pain and its effect on the work of the operators as responded by them in the survey.

Also, about 22.2 percent of the sample says that they experience occasional numbness due to long hours of operating on tractors, while 27.8 percent of the sample

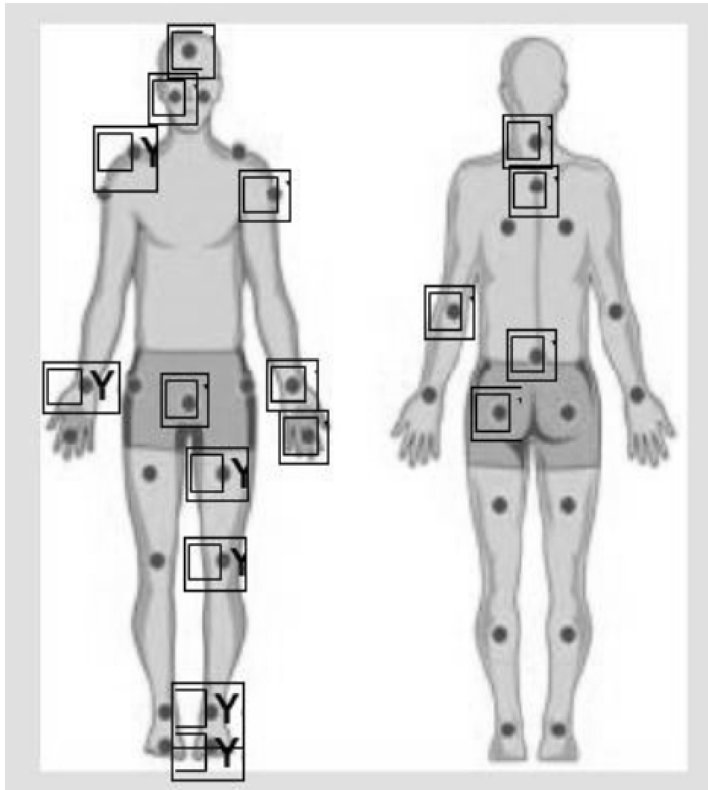


Figure 3: Layout of pain ratings

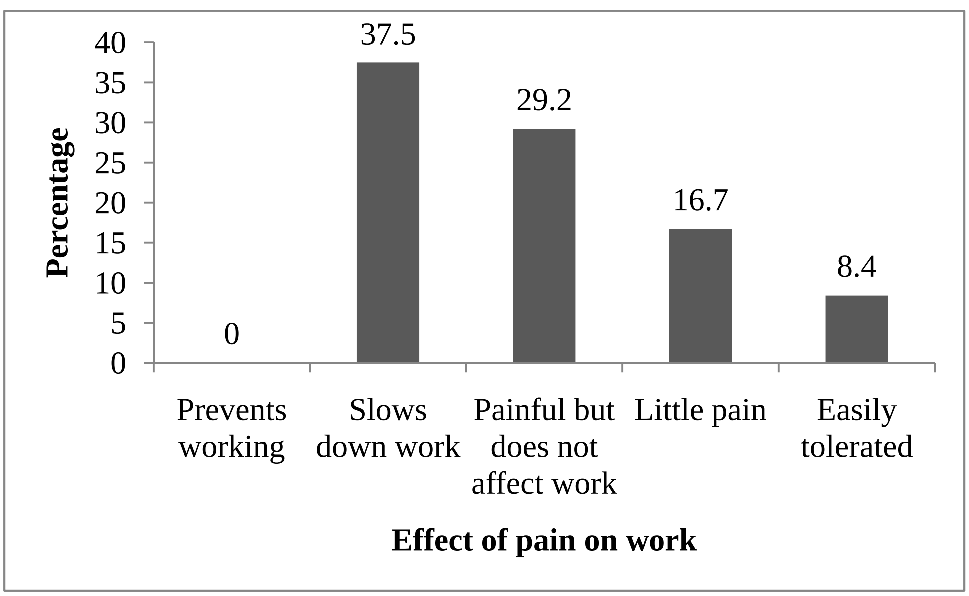


Figure 4: Effect of pain on work

says they seldom feel the numbness. Also, around 2.8 percent agree that they occasionally lose balance and fall while mounting or dismounting, while 72.2 percent admit that they have never lost balance. Figure 5 shows the results for the frequency at which the tractor operators experienced imbalance or dizziness.

A select number of design aspects of various tractors and human factors related to cab use were also included in the survey. About 58.3 percent of operators admit that they occasionally press wrong levers or controls due to confusing location of the controls. Thirty percent say that they seldom press wrong levers while 11.1 percent agree that they never pressed wrong controls. Figure 6 shows the responses for the frequency at which the operators press wrong buttons or levers.

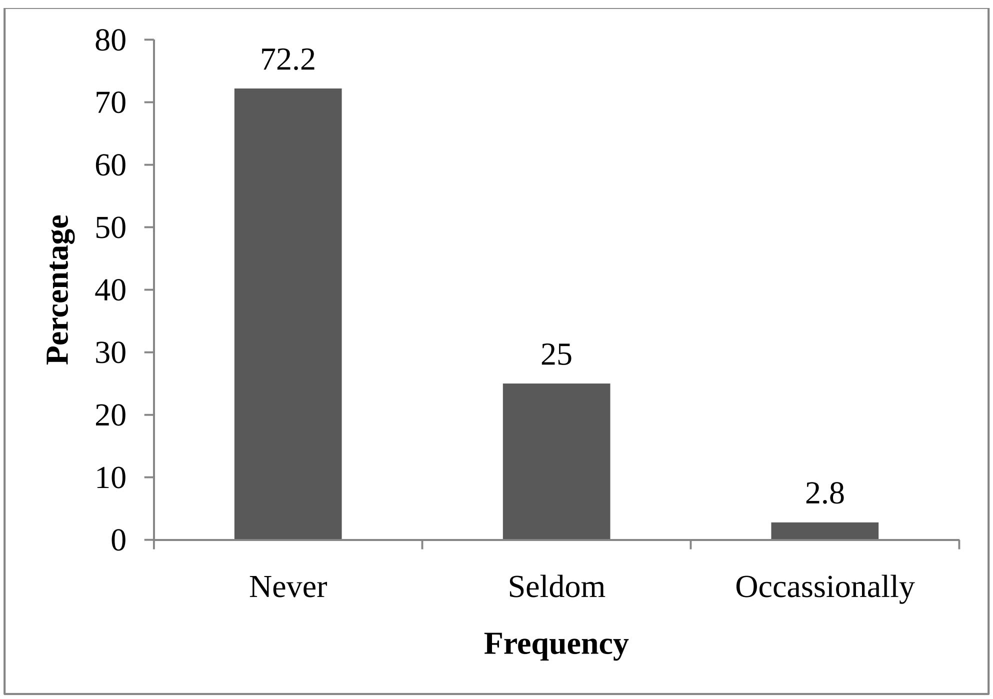


Figure 5: Frequency at which imbalance or dizziness is experienced

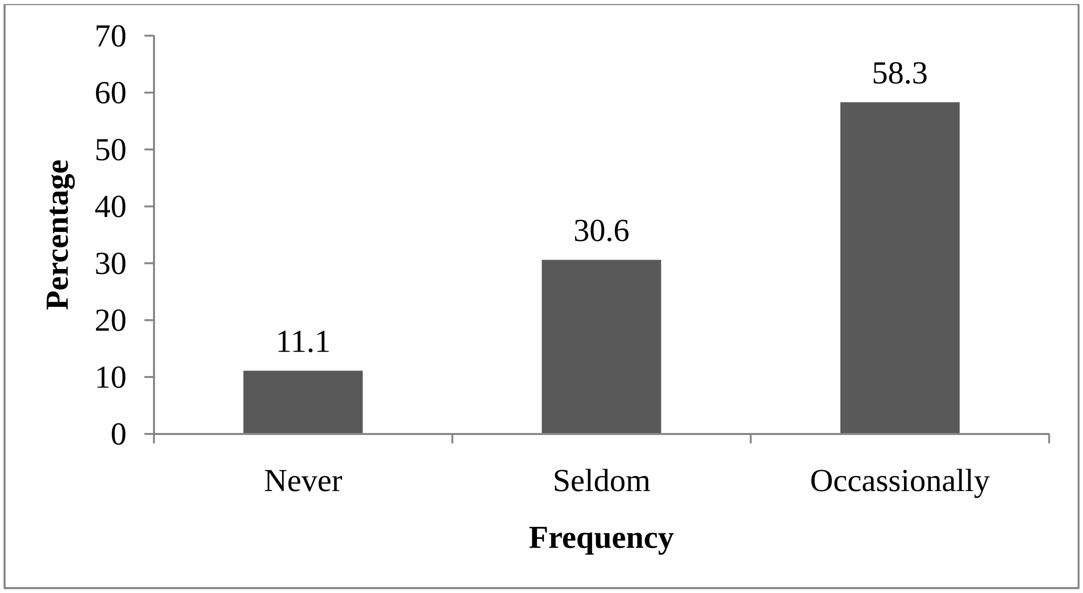


Figure 6: Frequency at which wrong buttons or levers are pressed

When asked about the flexibility of the tractor seats, 75 percent report that their tractors have adjustable seats to accommodate different operators, and that almost 88.9 percent of the users adjust their seats accordingly. Figure 7 shows the percentage of people who adjust their seats. When questioned whether the operators rotate in their seats to look behind, about 58.3 percent said that they often rotate to look behind, while 16.7 percent said they occasionally rotate and look behind. Of these, 41.7 percent of the operators agree that their tractor seats are designed to rotate, while 44.4 percent admitted that their tractor seats were not designed to rotate. Among those whose tractors seats do not rotate, 33.3 percent admitted to have wished they had the seats with a greater degree of freedom for rotation. About 83.3 percent of operators admit that their tractors have adjustable steering wheels and that all of them adjust the wheel, while 16.7 percent say that their tractors are not equipped with adjustable steering wheels.

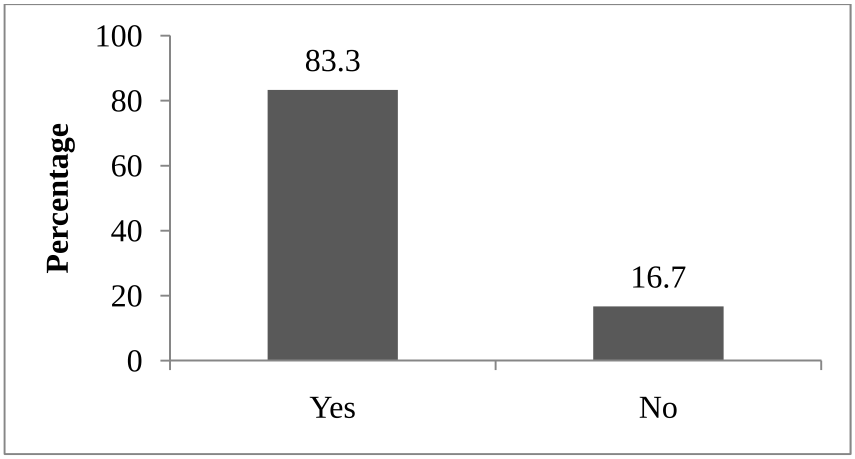


Figure 7: Percentage of people who adjust their tractor seats

When asked if there were any controls or levers that were hard to reach, 25 percent of the operators replied that their tractors had some controls which were hard to reach, and among these, about 41.6 percent admitted that this affected the operation of tractors. It was observed that the models which had controls that were hard to reach were usually John Deere and Ford. Figure 8 shows whether there was any effect of controls on operation of tractors.

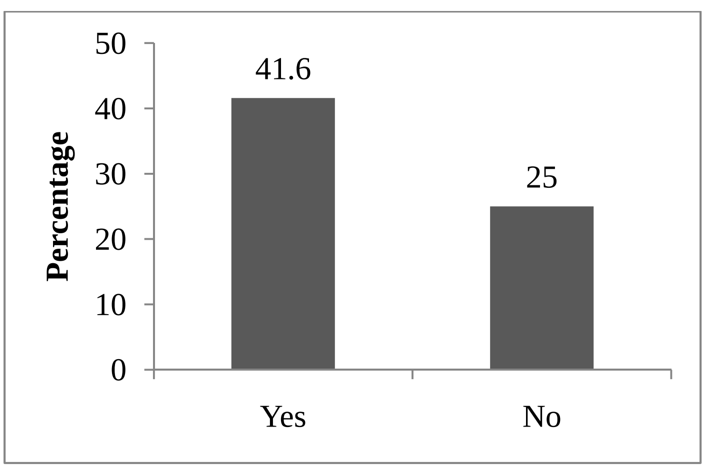


Figure 8: Effect of imperfectly placed controls on operation of tractors

Moreover, about 55.5 percent of the operators claimed that there were other suitable locations in which these controls could have been placed, while 11.2 percent thought that there was nowhere else that these controls could have been placed in order to make it easier for the operators to reach them.

When the operators were asked if they ever slipped and caught themselves before falling from the tractor while mounting/dismounting, 72.2 percent answered that they slipped but avoided falling while mounting, while 83.3 percent said that they have slipped but avoided falling while dismounting. Moreover, about 41.7 percent reported that they slipped and fell off the tractor while mounting, while 58.3 percent indicated that they slipped and fell while dismounting the tractor.

Figure 9 shows the percentage of people who slipped and caught themselves before falling while mounting/dismounting. Figure 10 shows the percentage of people who slipped and fell off the tractor while mounting/dismounting.

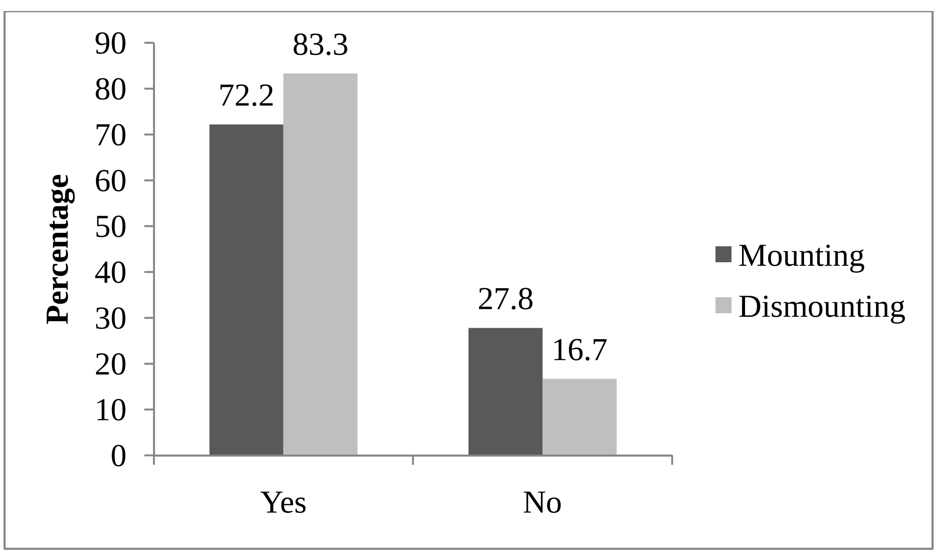


Figure 9: Percentage of slips without falls while mounting/dismounting

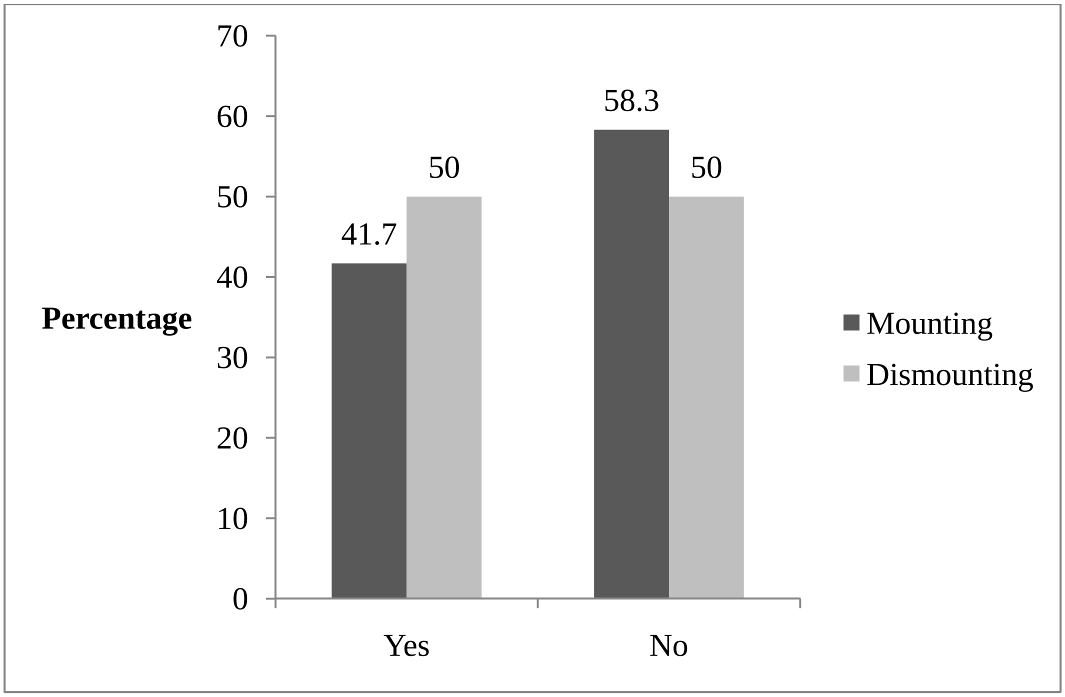


Figure 10: Percentage of falls while mounting/dismounting

Also, it was observed that summer was the season where there were the maximum number of slips and falls. Around 33.4 percent of people admitted that they slipped off the tractor steps in summer. This was followed by winter, wherein the tractor operators might be at an increased risk of slips and falls due to the snowing conditions in various regions. Figure 11 summarizes the proportion of falls that were reported by the operators in various seasons of the year.

According to the responses given by the operators, evening was the time of the day where the maximum proportion of slips and falls were reported. This might have been due to the lack of proper lighting conditions on the farm. Figure 12 reports the proportion of slips and falls that took place during various times of the day.

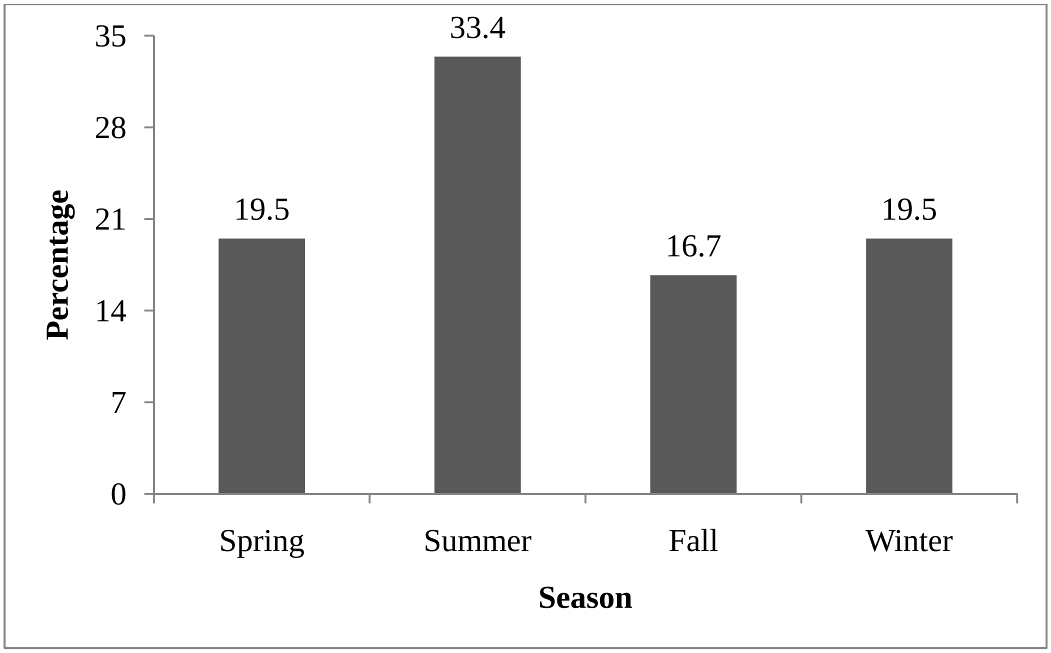


Figure 11: Proportion of slips and falls during season

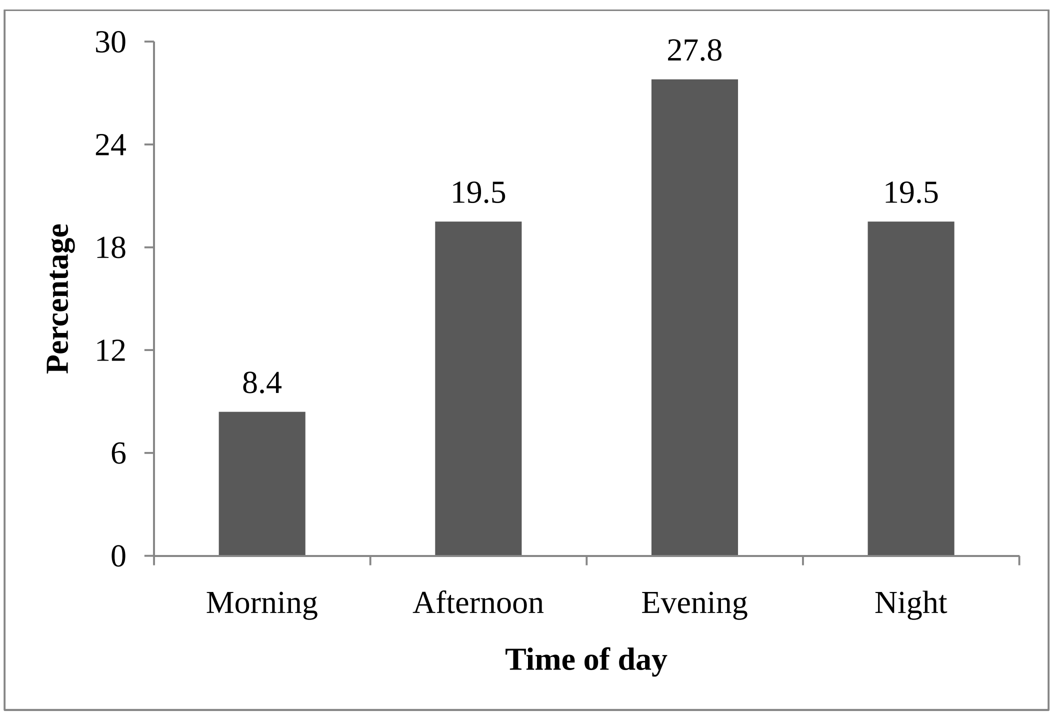


Figure 12: Proportion of slips and falls during the time of day

3.4 Statistical Analyses

After completion of the descriptive statistics, the survey responses were analyzed for any statistical significance in the outcome. For this purpose, a very popular statistical software called JMP, version 7.0 (developed by the SAS Institute) was utilized. Various tests like ANOVA and Bi-variate analyses were used to distinguish any significant variation among the means of different groups. Also, they were verified to see if there was any significant relation between various factors.

For this purpose, the ages of the participants were categorized into 7 groups. Participants of 18-24 years fall under category ‘A’, 25-30 years fall under ‘B’, 31-36 years fall under ‘C’, 37-42 years fall under ‘D’, 43-48 years fall under ‘E’, 49-54 years fall under ‘F’, and participants greater than 55 years fall under ‘G’. 30.6 percent of the sample fell under category ‘A’. The frequency distribution of the age categories is shown in Figure 13.

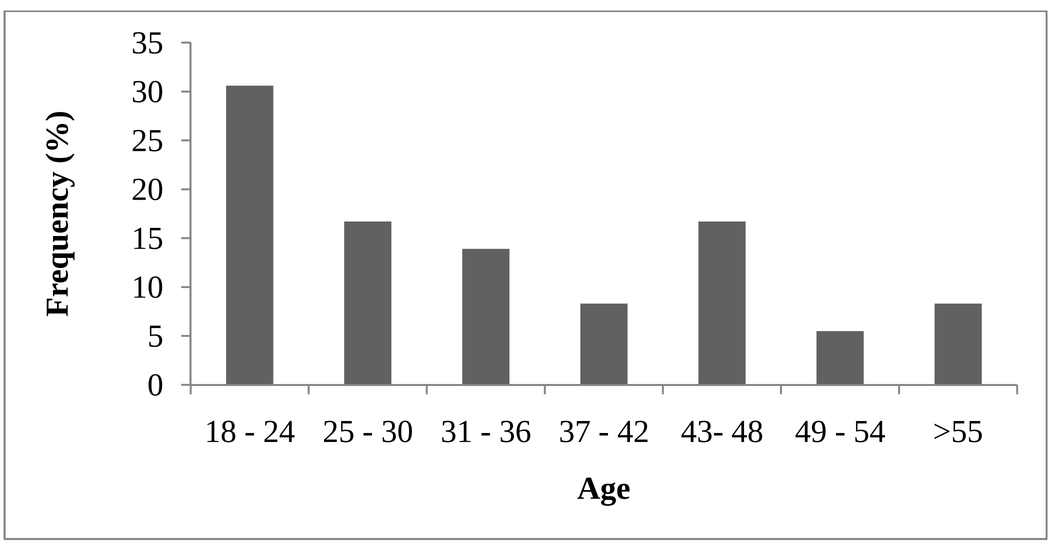


Figure 13: Frequency distribution of age categories

Tests using ANOVA were conducted on various factors for which the age of the participant might have had an influence. The one-way ANOVA between age and pains of different body parts have been performed.

3.4.1 One-way Analysis of Ankle Pain by Age

Figure 14 shows the box-plot analysis and the ANOVA test of the Ankle Pain and Age. Generally, a p-value of <0.05 indicates that there is a significant relation between the two factors. In this case, p = 0.5042 in Table 4 shows that there is no significance between the Age and Ankle Pain. Actually, the Ankle Pain was reported by around 19.5 percent of the population.

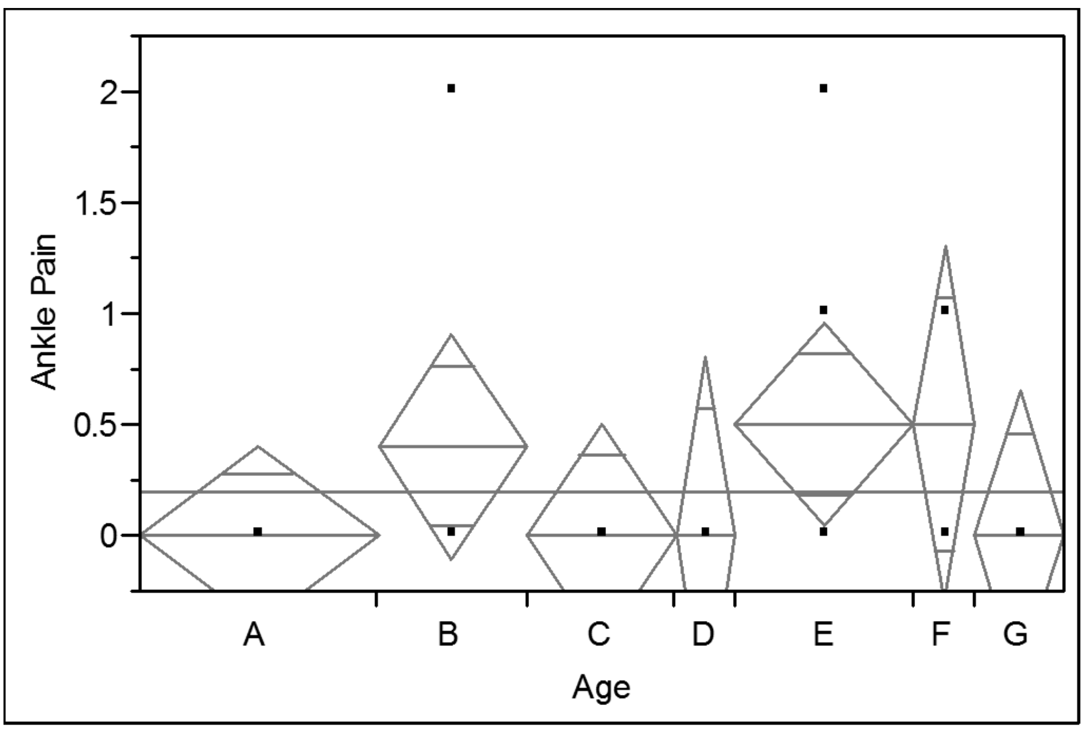


Figure 14: ANOVA analysis for age by ankle pain

Table 4: ANOVA analysis for age by ankle pain

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob> F
Age	6	1.6387	0.2731	0.9104	0.5042
Error	24	7.2000	0.3000		
C. Total	30	8.8387			

Hence, there is a chance of assuming that there could be significant relation between the age and the ankle pain. But, the ANOVA test proves otherwise. Similarly, the ANOVA test has been used to verify if there was a significant relation between Age and Knee Pain.

3.4.2 One-way Analysis of Knee Pain by Age

Figure 15 shows the ANOVA analysis of Knee Pain and Age, which was reported by around 30.6 percent. But, from the probability value of 0.0608 shown in Table 5, it can be inferred that there is no significant relation between the Age and the Knee Pain; however, this value is approaching significance. The maximum pain was reported only in certain parts of the body like lower back, upper back, neck, shoulder, hips, thighs, elbows, and upper arms. The participants did not feel, or felt minimum pain in certain parts of the body like wrists, feet, head, eyes, fingers, and groin. The analysis of only a few of the body parts has been discussed in this report, as an example of the most significant findings.

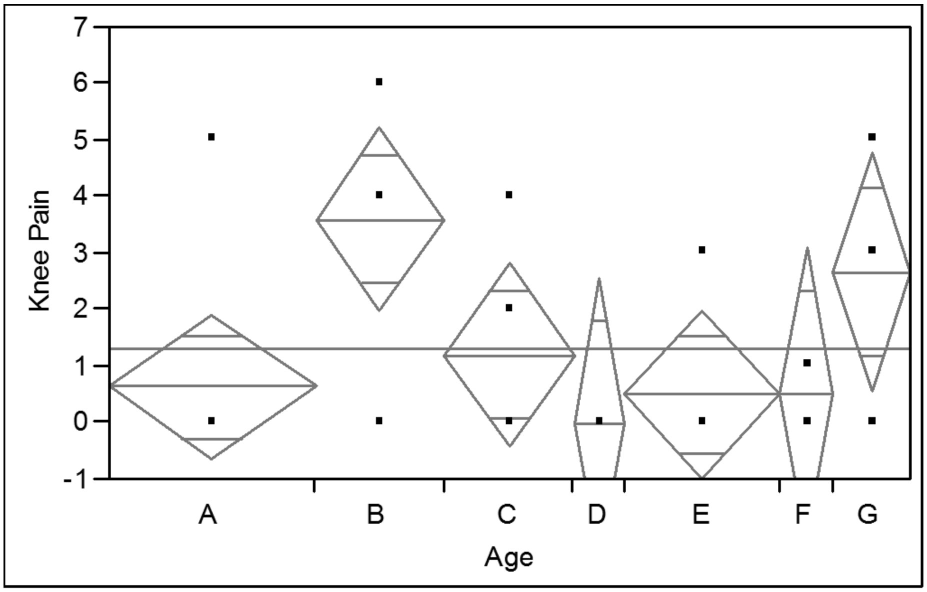


Figure 15: ANOVA analysis for age by knee pain

Table 5: ANOVA analysis for age by knee pain

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob> F
Age	6	44.23253	7.37209	2.3736	0.0608
Error	24	74.54167	3.10590		
C. Total	30	118.77419			

3.4.3 One-way Analysis of Neck Pain by Age

The Neck Pain, which had occupied the second place, has been reported by almost 41.7 percent of the sample. But, the ANOVA test (Figure 16) shows a probability value of 0.0145 as shown in Table 6. The p-value being less than 0.05 shows that there is a significant relation between the Neck Pain and various age groups.

Similarly, the ANOVA analysis has been conducted on various body parts with respect to age of the tractor operators. Table 7 lists the probability values of all the ANOVA analyses and their significance.

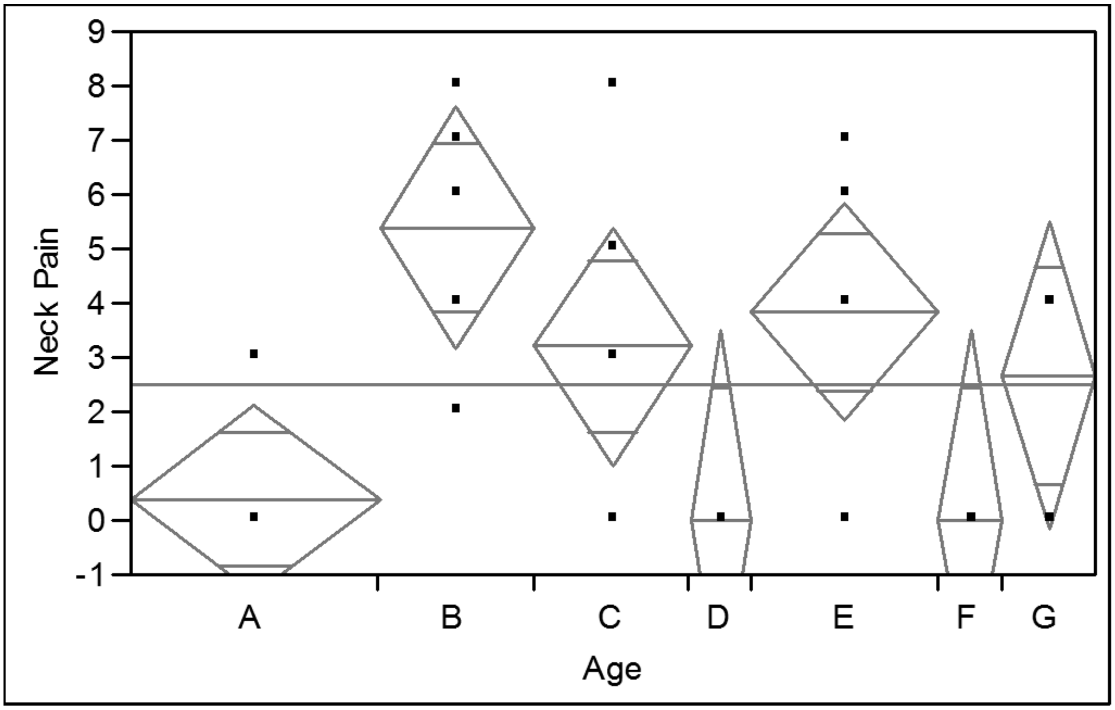


Figure 16: ANOVA analysis for age by neck pain

Table 6: ANOVA analysis for age by neck pain

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob> F
Age	6	116.3669	19.3945	3.3883	0.0145
Error	24	137.3750	5.7240		
C. Total	30	253.7419			

Table 7: ANOVA analysis values for different body arts with age

	F Ratio	Significance	% of sample who reported Pain
Ankle Pain	0.9104	0.5042	19.50%
Knee Pain	2.3736	0.0608	30.60%
Thigh Pain	0.7675	0.603	5.50%
Hip Pain	0.7986	0.5809	5.60%
Groin Pain	0	0	2.70%
Finger Pain	1.1026	0.3896	8.40%
Wrist Pain	0.8223	0.5638	8.40%
Elbow Pain	0.6725	0.6728	5.50%
Upper Arm Pain	2.1473	0.0847	13.90%
Shoulder Pain	1.5409	0.2078	30.50%
Neck Pain	3.3883	0.0145	41.70%
Eyes Pain	0.5765	0.7452	11.20%
Head pain	0.9523	0.4774	8.40%
Upper Back Pain	0.6573	0.6842	38.90%
Low Back Pain	0.6417	0.696	77.80%
Buttock Pain	1.2611	0.3118	38.90%
Feet Pain	0	0	2.70%

Additional analyses have been conducted to check if the amount of time spent per day working on the tractor by an individual could affect the health of the tractor operators. The following analyses show the ANOVA done on the time spent on the tractors and different body pains.

3.4.4 One-way Analysis of Ankle Pain by Time Spent

Figure 17 shows the One-way ANOVA analysis of the Ankle Pain by Time Spent. The p-value in Table 8 is greater than 0.05, which indicates that there is no significant relation between the time spent on the tractor per day and the ankle pain.

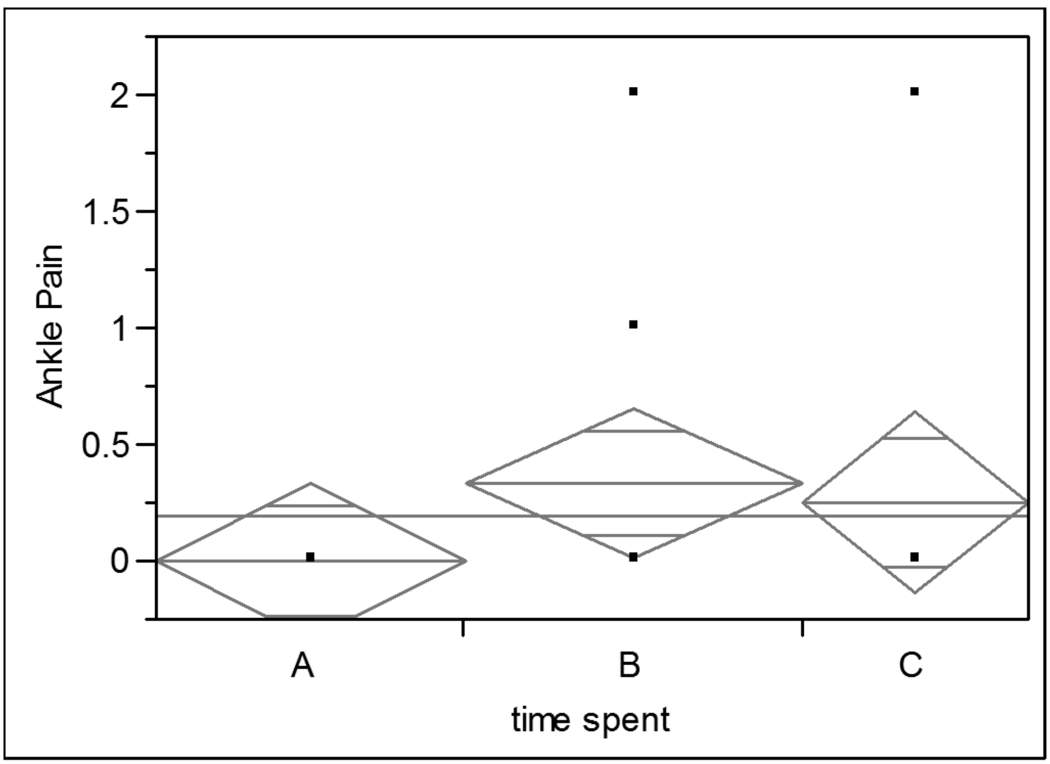


Figure 17: ANOVA analysis for time spent by ankle pain

Table 8: ANOVA analysis for time spent by ankle pain

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob> F
time spent	2	0.6720	0.3360	1.1521	0.3305
Error	28	8.1667	0.2916		
C. Total	30	8.8387			

3.4.5 One-way Analysis of Upper Back Pain by Time Spent

Figure 18 shows the One-way analysis of Upper Back Pain by Time Spent. The probability value calculated in the ANOVA analysis in the Table 9 is greater than 0.05. This means there is no significant relation between the amount of time spent on the tractor per day and the upper back pain.

Similarly, all the other body parts were also analyzed using ANOVA in order to check if there was any influence of the amount of time spent by the operator on the tractor. Table 10 summarizes the ANOVA values for all the body parts with respect to the amount of time spent on the tractor by the operator.

Another important factor that could be analyzed was the influence that the frequent rotation in the seat had on pain ratings. The statistics indicate that about 59 percent of the operators often rotate in their seats to look behind for some reason. Among them, only 59 percent of the operators have the facility to rotate the seats properly. This means that the tractors with no facility of rotating seats pose difficulty for the operators who frequently rotate. The analyses discussed below show the influence of frequent rotation in the seat on some of the pain ratings.

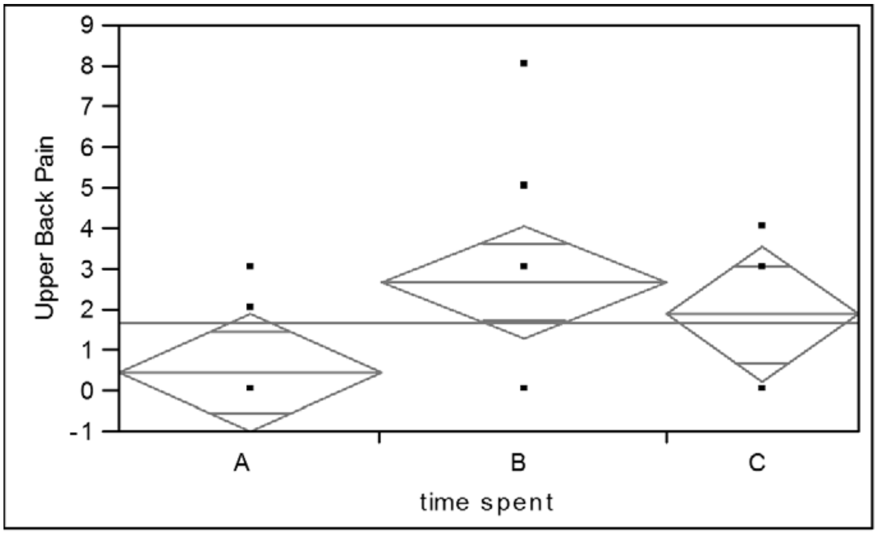


Figure 18: ANOVA analysis for time spent with upper back pain

Table 9: ANOVA analysis for time spent with upper back pain

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob> F
time spent	2	28.5052	14.2526	2.6557	0.0879
Error	28	150.2689	5.3667		
C. Total	30	178.7741			

3.4.6 One-way Analysis of Low Back Pain by Frequency of Rotation in Seat

Figure 19 shows the One-way analysis of Low Back Pain by Frequency of Rotation in Seat. Since the probability value shown in Table 11 is greater than 0.05, it could be concluded that there is no significant influence of frequency of rotation in the seat on the Lower Back. Similarly, it was also verified if there was any influence of the frequency of rotation in the seat on all the other possible body parts. The results are summarized in Table 12.

Table 10: ANOVA values for different body parts with time spent on the tractor

	F Ratio	Significance
Ankle Pain	1.1521	0.3305
Knee Pain	2.2354	0.1257
Thigh Pain	0.7089	0.5011
Hip Pain	0.7634	0.4882
Groin Pain	0	0
Finger Pain	0.6197	0.5453
Wrist Pain	0.5506	0.5827
Elbow Pain	0.9737	0.3901
Upper Arm Pain	1.4285	0.2566
Shoulder Pain	1.3523	0.2819
Neck Pain	0.1698	0.8447
Eyes Pain	0.555	0.5803
Head pain	0.2421	0.7866
Upper Back Pain	2.6557	0.0879
Low Back Pain	0.1334	0.8757
Buttock Pain	2.5261	0.098
Feet Pain	0	0

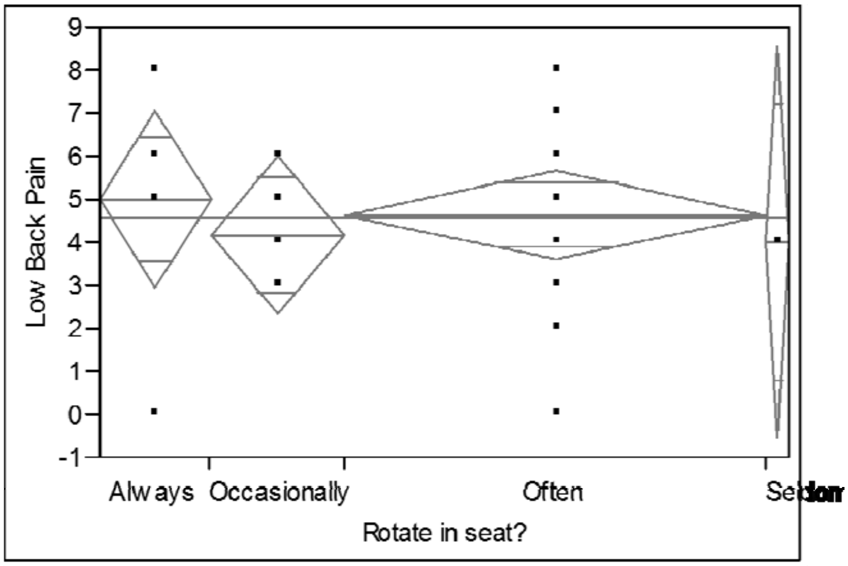


Figure 19: ANOVA for time spent on the tractor and the frequency of rotation

Table 11: ANOVA for time spent on the tractor and the frequency of rotation

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob> F
Rotate in seat?	3	2.2940	0.7646	0.1549	0.9256
Error	27	133.2543	4.9353		
C. Total	30	135.5483			

Table 12: ANOVA values for the frequency of rotation in seat on different body parts

	F Ratio	Significance
Low Back Pain	0.1549	0.9256
Upper Back Pain	0.2209	0.881
Head Pain	0.9695	0.4215
Shoulder Pain	0.6421	0.5946
Upper Arm Pain	0.4318	0.732
Elbow Pain	0.623	0.6063
Neck Pain	1.1255	0.3562

Also, Bi-variate fit analysis for the BMI and different body parts has been done.

3.4.7 Bi-variate Fit for Ankle Pain by BMI

Figure 20 shows the Bi-variate fit for Ankle Pain compared to BMI. The probability value p = 0.4857 shown in Table 13 is less than 0.05, which shows that there is no significant influence of BMI on Ankle Pain experienced by the operators. Similarly, Table 14 summarizes the Bi-variate fit for different body parts with BMI.

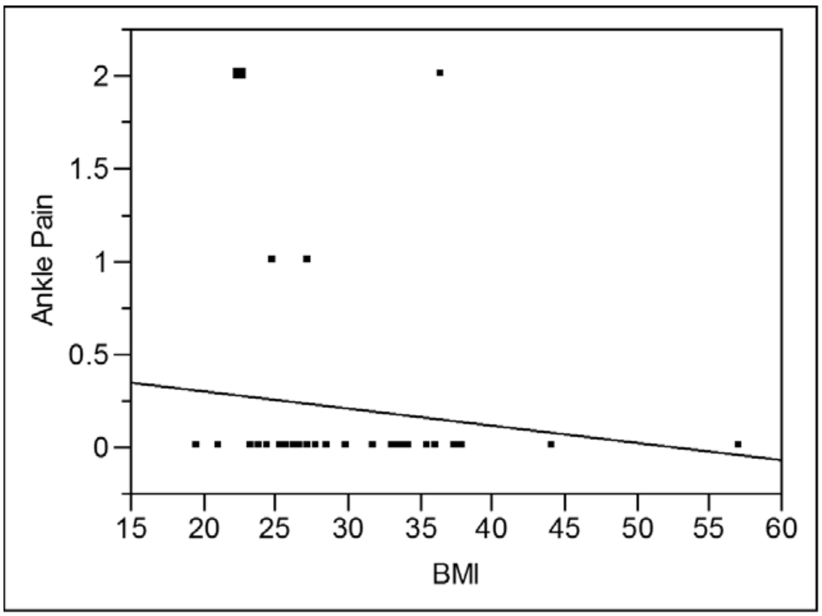


Figure 20: Bi-variate fit for ankle pain by BMI

Table 13: Bi-variate fit for ankle pain by BMI

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.1494	0.1494	0.4988
Error	29	8.6892	0.2996	Prob> F
C. Total	30	8.8387		0.4857

Table 14: Bi-variate fit for different body parts with BMI

	Significance	F Ratio
Ankle Pain	0.4857	0.4988
Knee Pain	0.3571	0.8757
Thigh Pain	0.2727	1.2519
Hip Pain	0.2726	1.2526
Groin Pain	0	0
Finger Pain	0.851	0.3639
Wrist Pain	1.3048	0.2627
Elbow Pain	0.2421	1.426
Upper Arm Pain	0.8168	0.0546
Shoulder Pain	0.8296	0.0472
Neck Pain	0.5839	0.3068
Eyes Pain	2.6784	0.1125
Head pain	0.3029	1.1001
Upper Back Pain	0.7887	0.0731
Low Back Pain	0.7442	0.1085
Buttock Pain	0.3939	0.7489
Feet Pain	0	0

Additionally, Tukey Kramer HSD (Honestly Significant Difference) test has also been conducted as a post-hoc analysis to compare all possible group means. The test could be analyzed using the comparison circles plot, which is a visual comparison of group mean plots. Each pair of group means can be compared visually by examining how the comparison circles intersect. The outside angle of intersection tells whether group means are significantly different. Figure 21 shows the angle of intersection and significance.

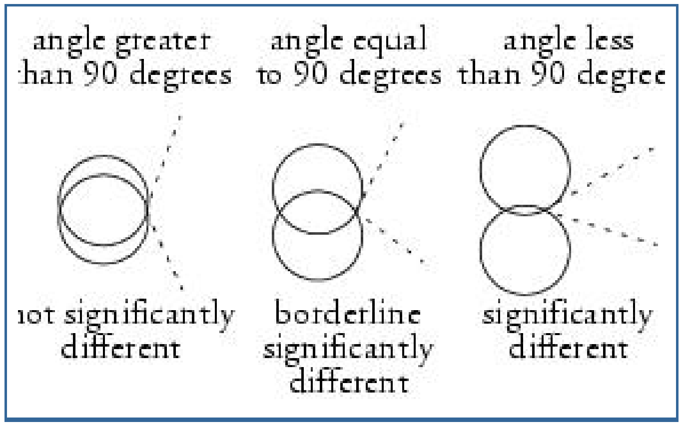


Figure 21: Angle of intersection and significance

3.4.8 Tukey Kramer HSD Post-hoc Analysis for Neck Pain with Age

Figure 22 shows the comparison circles plot. According to the intersection of the circles, no groups are significant. But the probability value p = 0.0145 shown in Table 15 is less than 0.05, which means that it is significant. All the values in the table are negative except for the groups A and B, which are positive. This means that the groups A and B are significantly different.

Table 16 shows the Tukey Kramer analysis for all the body parts with age, along with significantly different groups.

Similar to age, the amount of time spent on the tractor per day by an operator has also been classified into three categories. Operators who spend between 0 to 5 hours per day on the tractor fall under category ‘A’, those who spend between 5.1 to 10 hours per day fall under category ‘B’, and those operators who spend more than 10 hours per day fall under category ‘C’. According to the responses received, about 34.5 percent of the sample fell under category ‘A’, about 48.3 percent of the sample fell under ‘B’, and about 17.3 percent of the sample fell under the category ‘C’.

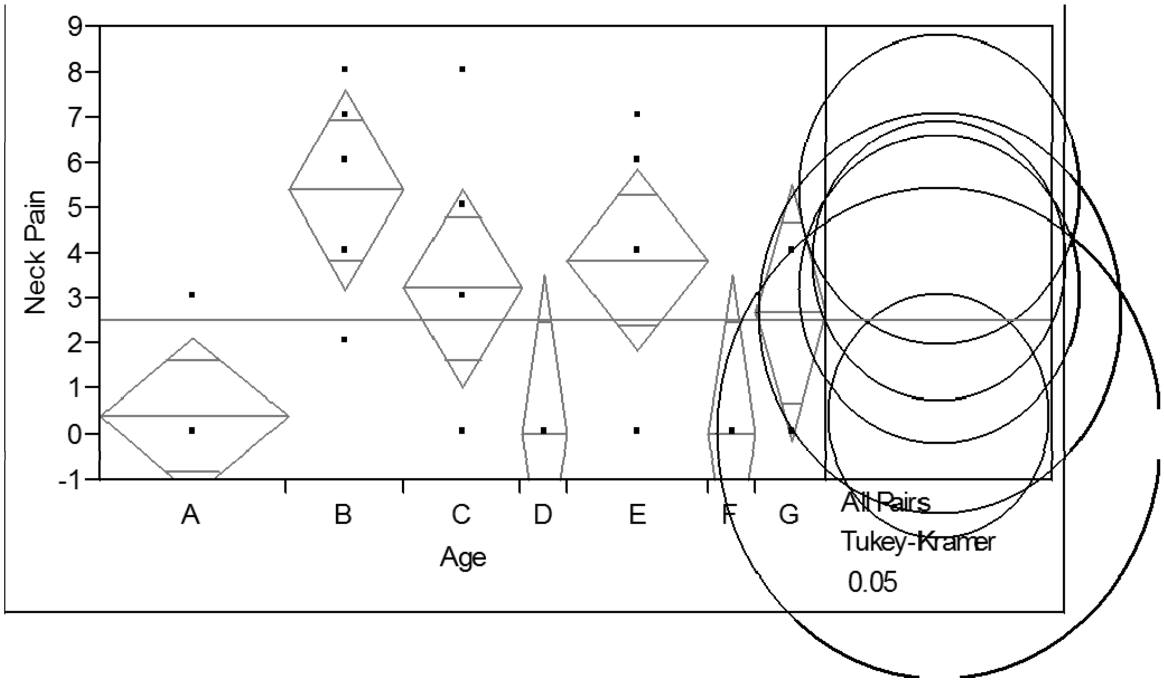


Figure 22: Tukey Kramer analysis for neck pain with age

Table 15: Tukey Kramer analysis for neck pain with age

Abs(Dif)-LSD	**B**	**E**	**C**	**G**	**A**	**F**	**D**
B	-4.8590	-3.0855	-2.6590	-2.8773	0.6452	-1.0278	-1.0278
E	-3.0855	-4.4356	-4.0188	-4.2658	-0.6908	-2.4396	-2.4396
C	-2.6590	-4.0188	-4.8590	-5.0773	-1.5548	-3.2278	-3.2278
G	-2.8773	-4.2658	-5.0773	-6.2729	-2.9096	-4.3467	-4.3467
A	0.6452	-0.6908	-1.5548	-2.9096	-3.8414	-5.6987	-5.6987
F	-1.0278	-2.4396	-3.2278	-4.3467	-5.6987	-7.6827	-7.6827
D	-1.0278	-2.4396	-3.2278	-4.3467	-5.6987	-7.6827	-7.6827

Positive values show pairs that are significantly different

Table 16: Tukey Kramer analysis for different body parts with age

	Significance	Significantly different groups
Ankle Pain	0.5042	None
Knee Pain	0.0608	None
Thigh Pain	0.603	None
Hip Pain	0.5809	None
Groin Pain	0	None
Finger Pain	0.3896	None
Wrist Pain	0.5638	None
Elbow Pain	0.6728	None
Upper Arm Pain	0.0847	None
Shoulder Pain	0.2078	None
Neck Pain	0.0145	A and B
Eyes Pain	0.7452	None
Head pain	0.4774	None
Upper Back Pain	0.6842	None
Low Back Pain	0.696	None
Buttock Pain	0.3118	None
Feet Pain	0	None

Similarly, the severity of the pain has also been classified into four categories, namely, ‘Easily tolerated’, ‘Little pain’, ‘Painful but does not affect work’, and ‘Slows down work’. A mosaic plot, a graphical display which allows one to examine the relationship among two or more categorical variables, has been created. Figure 23 shows the relationship between the time spent on the tractor by the operator per day and the effect of severity of the pain that has been caused to them.

From the mosaic plot shown in Figure 23, it can be inferred that the tractor operators who had spent more than 10 hours per day had been more affected, which

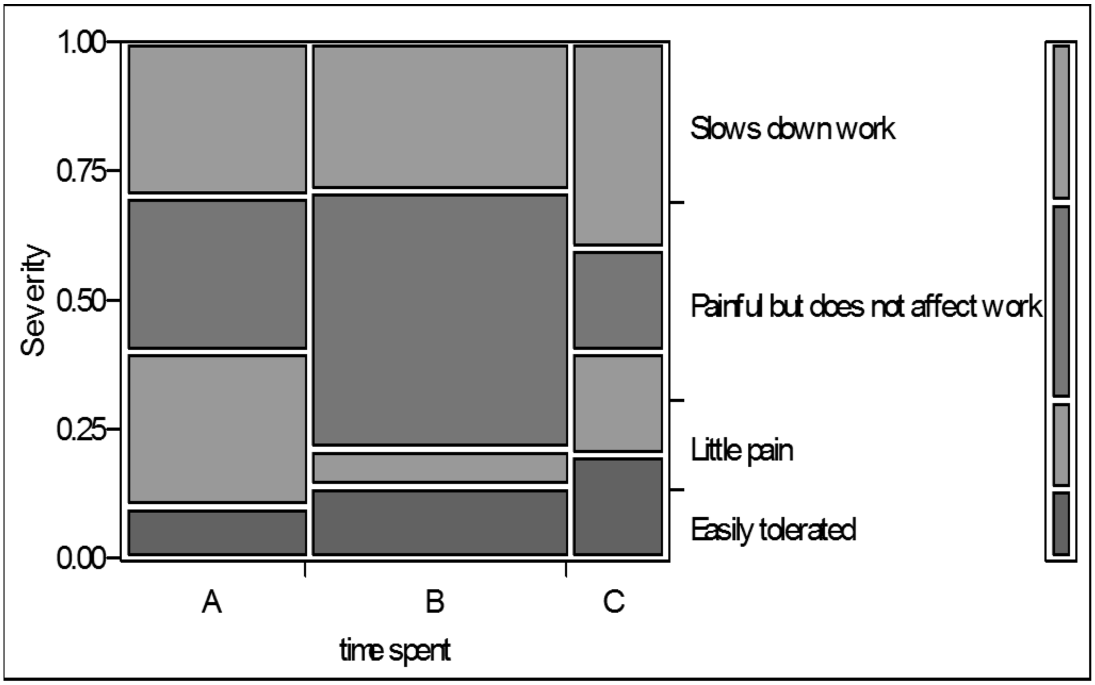


Figure 23: Mosaic plot for the effect of time spent on work

caused about 65 percent of the sample to slow down the work. Also, 50 percent of the sample who spent 5-10 hours per day on the tractors admitted that the work is very painful but it does not really affect the work. It can also be noticed that there is only a small percentage of samples who could easily tolerate the pain. From the Pearson coefficient indicated in Table 17, it could be inferred that there is a high degree of correlation between the amount of time spent on the tractor by an operator per day and the severity of the pain caused.

Table 17: Pearson coefficient for effect of time spent on work

Test	Chi-square	Prob>ChiSq
Likelihood Ratio	3.428	0.7535
Pearson	3.328	0.7667

Similarly, a mosaic plot has also been created to analyze the relationship between the age of the operator and the severity of the pain.

Figure 24 shows the mosaic plot for the influence of age on the effect of work. It can be inferred that 50 percent of the tractor operators whose age groups are ‘D’, ‘F’, and ‘G’, i.e., more than 37 years of age, have been more affected, which could also cause them to slow down the work. Forty percent of the sample that fall under ‘A’ admits that the work is painful but they do not really stop the work. There is a small percentage of operators who reported that the pain is easily tolerated. On the contrary, from the value of Pearson coefficient in the Table 18, it could be inferred that there is a moderate degree of correlation between the age of the tractor operators and their pain ratings.

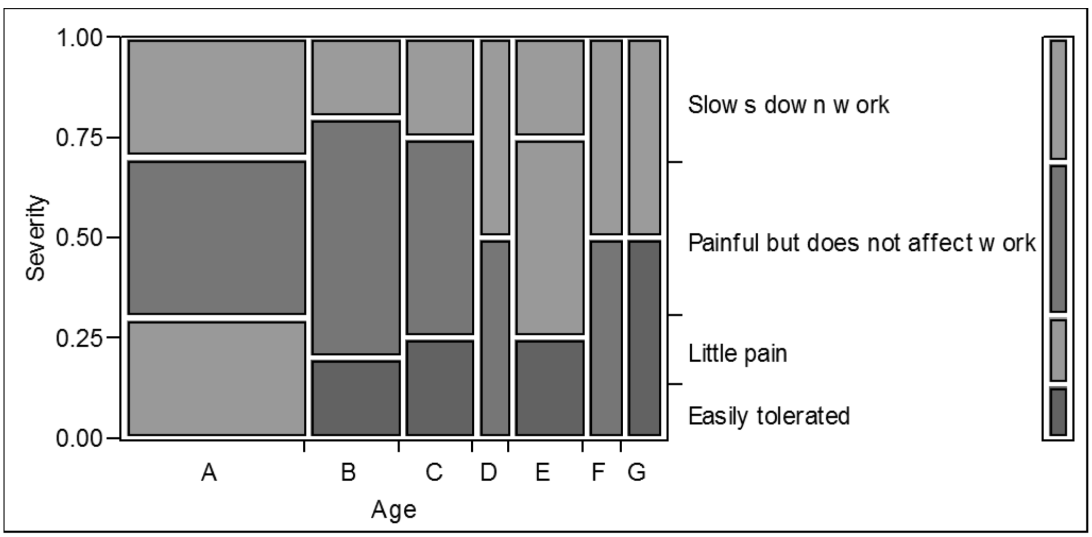


Figure 24: Mosaic plot for the effect of age on work

Table 18: Pearson coefficient for the effect of age on work

Test	Chi-square	Prob>ChiSq
Likelihood Ratio	19.581	0.3569
Pearson	14.945	0.6657

Next, a mosaic plot has also been created to analyze if the usage of the controls that were hard to reach had any influence on any pains in some body parts. From the mosaic plot in Figure 25, it could be inferred that 55 percent of the sample that had controls that were hard to reach also reported neck pain. Another mosaic plot has been created to analyze the influence that the wrongly placed controls had on upper back pain and the lower back pain. From the mosaic plot in Figure 26, it could be inferred that about 30 percent of the sample that had controls that were hard to reach also reported upper back pain.

From the mosaic plot shown in Figure 27, it could be inferred that about 45 percent of the sample were also affected with lower back pain also reported controls that were hard to reach.

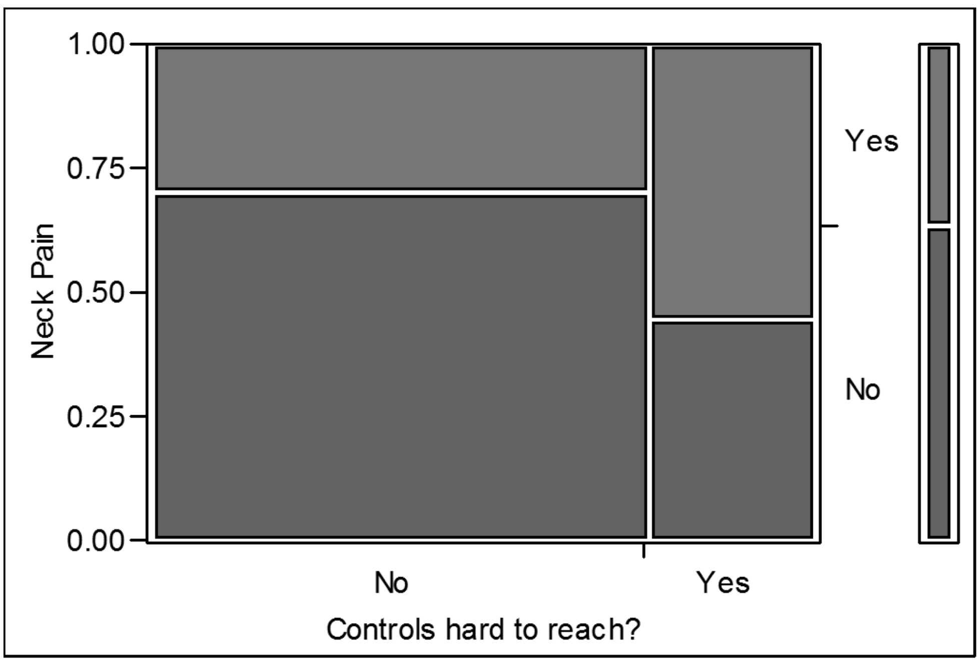


Figure 25: Influence of usage of controls on neck pain

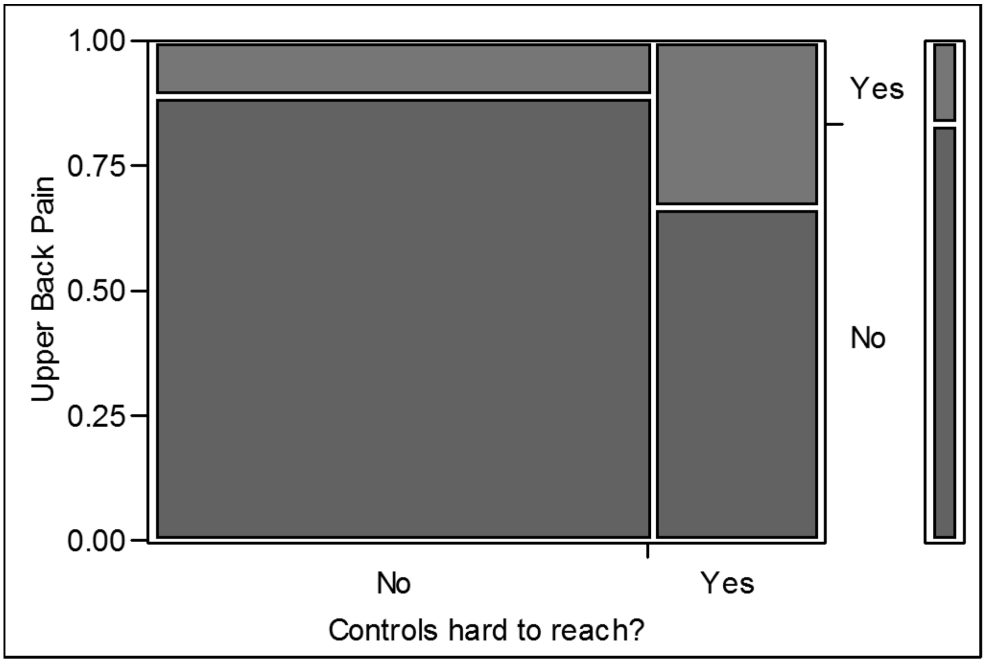


Figure 26: Influence of usage of controls on upper back pain

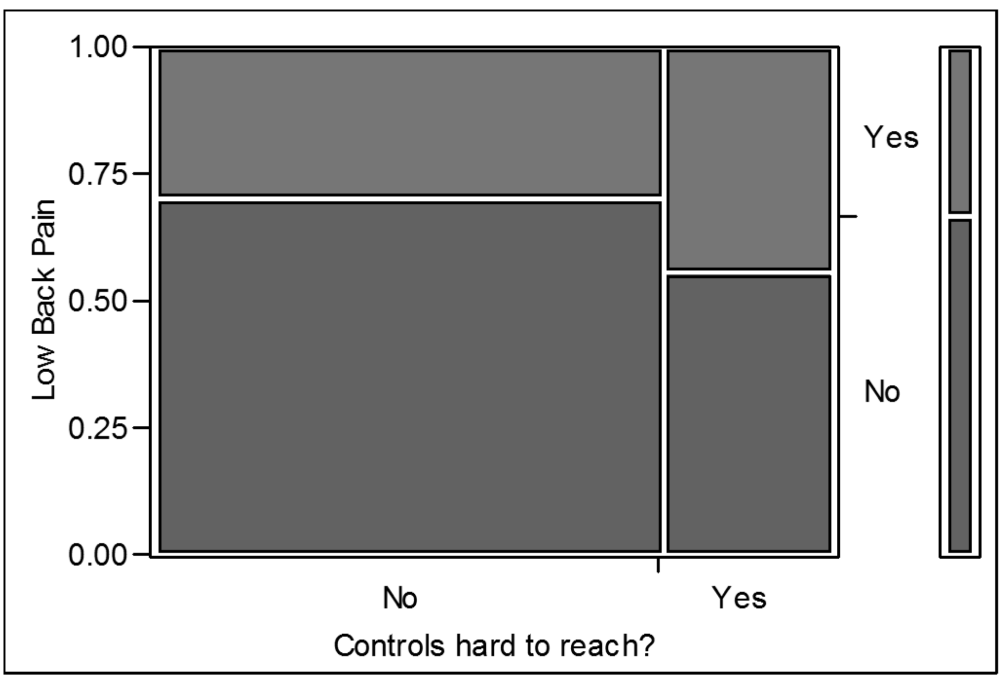


Figure 27: Influence of usage of controls on lower back pain

3.5 Discussions

Regarding the number of falls in a particular time of the day or a particular season of the year, it has been observed that most falls were reported in summer. The reason for the slips or falls in this season still remains unknown due to the lack of sufficient data. Since summer is a harvest season, there is a possibility of the tractor operators working longer hours on the farm. Hence, the proportion of slips and falls might have increased in summer because of fatigue and increased exposure. Similarly, evening was the time of the day the most slips and falls were reported. This might be due to the poor lighting or fatigue. One shortcoming of the survey is the sample size. Due to a very low sample size of only 36, the results interpreted through this survey may not be representative of the whole population of tractor operators.

It is commonly reported that persons exposed to whole body vibrations have low back pain. In the case of tractor operators, since the tractors do not normally have a suspension system, the vibration levels are higher compared to the other vehicles operated on the road. Therefore, the tractor drivers are exposed to low frequency vibrations, making them vulnerable to low back pain (Shyamal Koley 2010). This exposure to whole body vibration for longer lengths may lead to muscle fatigue, which in turn might be one of the reasons for falls while dismounting.

4 FIELD STUDY

The second step of the methodology consists of a field study, conducted in southern Idaho with 15 tractor operators and 5 different tractor models. This protocol was approved by the Institutional Review Board of the University of Utah. All the participants were required to give an informed consent prior to the study and were compensated for their time and inconvenience. The tractor models included were JD 9400T, JD 8200, MX275, Ford 4600, and JD4450. The measurements for all the tractors were noted down and compared to the SAE J-185 standards that were discussed in Section 1.4.

4.1 JD 9400T

Figure 28 shows the picture of a participant mounting JD 9400T. The measurements are also discussed and compared to the design recommendations in SAE standards, which are shown in Table 19.

Figure 28: JD 9400T

Table 19: Comparison of JD 9400T measurements with SAE standards

Measurements	JD 9400T	SAE J-185
Distance from ground to bottom step	37.5"	max: 30" pref: 16"
Vertical distance between steps	9.75"	max: 16" pref: 12"
Depth of Step	6.5"	5"
Width of step	5.5"	min: 5" pref: 7"
Height of cab floor from ground	69.5"	
Height of cab floor from last step	5"	

When the measurements of JD 9400T are compared with the recommended SAE J-185 standards, it is found that the bottommost step is higher (37.5") than both the preferred height (16") and the maximum height (30"). This is due to the fact that the first two steps of JD9400T were broken and the operators have been using the tractor without replacing the steps. Also, the vertical distance between steps is lower than the preferred height. The width of the step is within the minimum and preferred heights.

4.2 JD 8200

Figure 29 shows the picture of a participant mounting the tractor model JD 8200. When the measurements of JD 8200 are compared to the recommended standards of SAE J-185, it is found that the bottommost step is well within the range, the preferred height being 16" and the maximum being 30". The vertical distance between the steps is 0.5" lesser than the preferred distance. The measurements, depth, and width of the step also do not conform to the preferred measurements. Table 20 summarizes the measurements of JD 8200 and its comparison with SAE J-185 standards.

Figure 29: JD 8200

Table 20: Comparison of JD 8200 measurements with SAE standards

Measurements	JD 8200	SAE J-185
Distance from ground to bottom step	18"	max: 30" pref: 16"
Vertical distance between steps	11.5"	max: 16" pref: 12"
Depth of Step	6"	5"
Width of step	4.5"	min: 5" pref: 7"
Height of cab floor from ground	56"	
Height of cab floor from last step		

4.3 MX 275

Figure 30 shows a picture of the tractor model MX 275. When the measurements of JD 8200 are compared to SAE J-185 standards, it is found that although the height of the bottommost step is more than the preferred height, it is well within the limits. The vertical distance between the steps is 0.5” less than the preferred distance. Even for this tractor, the measurements for width and depth of the step do not conform to the standard measurements. Table 21 shows the comparison for MX 275 and SAE standards.

Figure 30: MX 275

Table 21: Comparison of MX 275 measurements with SAE standards

Measurements	MX 275	SAE J-185
Distance from ground to bottom step	20"	max: 30" pref: 16"
Vertical distance between steps	11.5"	max: 16" pref: 12"
Depth of Step	7.5"	5"
Width of step	6.5"	min: 5" pref: 7"
Height of cab floor from ground	66.5"	
Height of cab floor from last step	11.5"	

4.4 FORD 4600

Figure 31 shows a picture of the tractor model FORD 4600. This tractor has only one step to get into the tractor. When the measurements of FORD 4600 are compared to SAE J-185 standards, it is found that although the height of the step is more than the preferred height, it is well within the limits. Even for this tractor, the measurements for width and depth of the step do not conform to the standard measurements, but are well within the limits. Table 22 shows the comparison for FORD 4600 and SAE standards.

Figure 31: FORD 4600

Table 22: Comparison of FORD 4600 measurements to SAE standards

Measurements	FORD 4600	SAE J-185
Distance from ground to bottom step	24"	max: 30" pref: 16"
Vertical distance between steps	NA	max: 16" pref: 12"
Depth of Step	7.5"	5"
Width of step	NA	min: 5" pref: 7"
Height of cab floor from ground	24"	
Height of cab floor from last step	NA	

4.5 JD 8420

Figure 32 shows a picture of the tractor model JD 8420. When these measurements are compared to SAE standards, it is found that although height of the bottom most step is more than the preferred height, it is well within the limits. The measurements of vertical distance between the steps, width, and depth of the steps also do not conform to the standards. Table 23 shows the comparison for JD 8420 and SAE standards.

Figure 32: JD 8420

Table 23: Comparison of JD 8420 measurements with SAE standards

Measurements	JD 8420	SAE J-185
Distance from ground to bottom step	19.5"	max: 30" pref: 16"
Vertical distance between steps	9.5"	max: 16" pref: 12"
Depth of Step	6.75"	5"
Width of step	6"	min: 5" pref: 7"
Height of cab floor from ground	59"	
Height of cab floor from last step	12"	

When all the tractors' measurements are compared among themselves and also individually with the SAE J-185 standards, it can be inferred that the tractor model JD 8200 conforms well to the limits, among all the other tractors. The measurements of distance from ground to bottom step, vertical distance between steps, and depth of step are closer to the preferred measurements. However, conforming to the standards alone may not decrease the risk of slips and trips while mounting or dismounting the tractor.

4.6 Methodology in Detail

For the purpose of this study, the 15 participants were divided into 2 groups. In the first group, 8 participants were asked to work with 3 tractor models at once production site, i.e., JD 9400T, JD 8420, and MX 275. In the second group, the remaining 7 participants were asked to work with the other two tractors, i.e., JD 8200 and FORD 4600, at the other production site. The operators were asked to mount and dismount each tractor 4 times: 3 times the way they normally mount/dismount and once in the opposite manner. All the participants were fitted with retro-reflective spherical markers on major anatomical landmarks of their body, similar to a modified Helen Hayes marker set commonly used for gait analysis. There were 15 body segments identified which included feet, lower legs, thighs, pelvis, trunk, head, upper arms, forearms, and hands; 6 lower body joint centers included ankles, knees, and hips. The three-dimensional motion of these 0.025m retro-reflective markers were recorded with 5 different Panasonic GS55 cameras positioned in different angles around the work place. These cameras were recording at 60 Hz. The movements were analyzed using a motion analysis system, ViconMotus 9.0 (ViconPeak, Centennial, CO).

ViconMotus 9.0 motion analysis system was used to study the movements of the operators mounting and dismounting the tractors. Before the 4 trials, a calibration frame with 28 predetermined points was placed on the experimental area and recorded on video for defining the parameters of the camera system for 3D transformation. The experiments were calibrated for every different tractor and operator. Additionally, the ingress/egress and ankle/wrist trajectories of a randomly select participant for each of the tractors were recorded.

4.7 Results

4.7.1 General Observations

The patterns of mounting and dismounting were observed for all the 15 participants for different tractors. Also, the statistics regarding the number of participants who faced the cab or faced away from the cab during ingress/egress, or maintained 3-point contact while mounting/dismounting the tractor were recorded. Since all the operators mounted the tractor while facing the cab, it was also observed that all the participants maintained 3-point contact during ingress. Therefore, the egress of all the participants has been recorded for all the tractors. For the tractor model MX 275, 6 out of 8 participants dismounted facing away from the cab, and 4 subjects maintained 3-point contact. For the model JD 8420, all the 8 subjects dismounted the tractor while facing away from the cab, and 3 subjects maintained 3-point contact. For the model JD 9400T, 4 out of 8 subjects faced the cab while dismounting, and 6 participants maintained 3-point contact. For the model JD 8200, all the 7 subjects dismounted the tractor while facing away from the cab, and 5 subjects maintained 3-point contact. For FORD 4600, 2 subjects faced the cab while dismounting the tractor. Figure 33 summarizes the statistics of the participants while dismounting the tractors.

4.7.2 JD 8200

4.7.2.1 Ingress

The Figure 34 shows the ingress of a select participant on JD 8200. The Figures (a), (b), (c), and (d) show the stick figure of ingress of the participant at different time points. Figure (e) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is mounting the tractor.

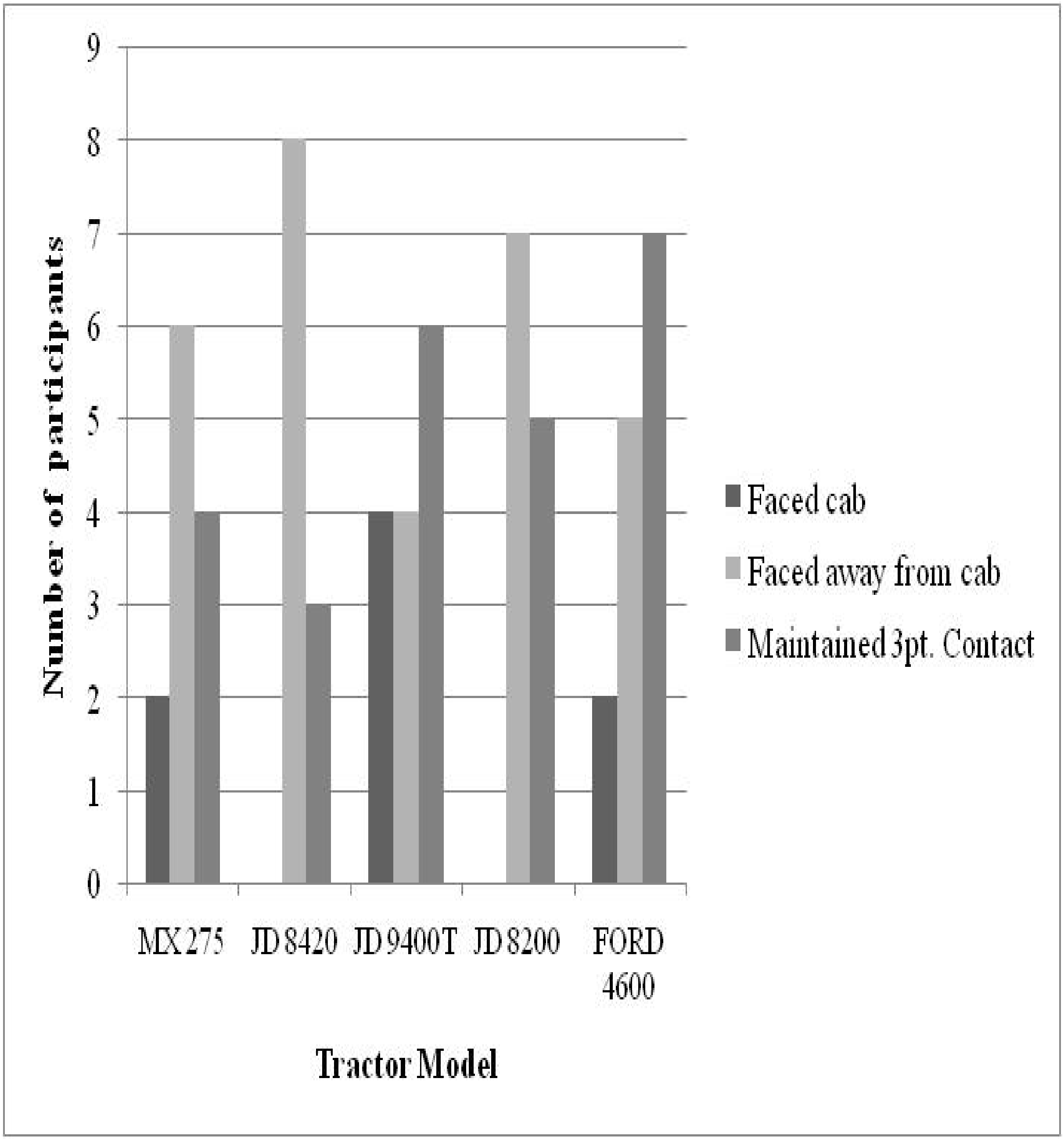


Figure 33: General observations of participants while dismounting the tractors

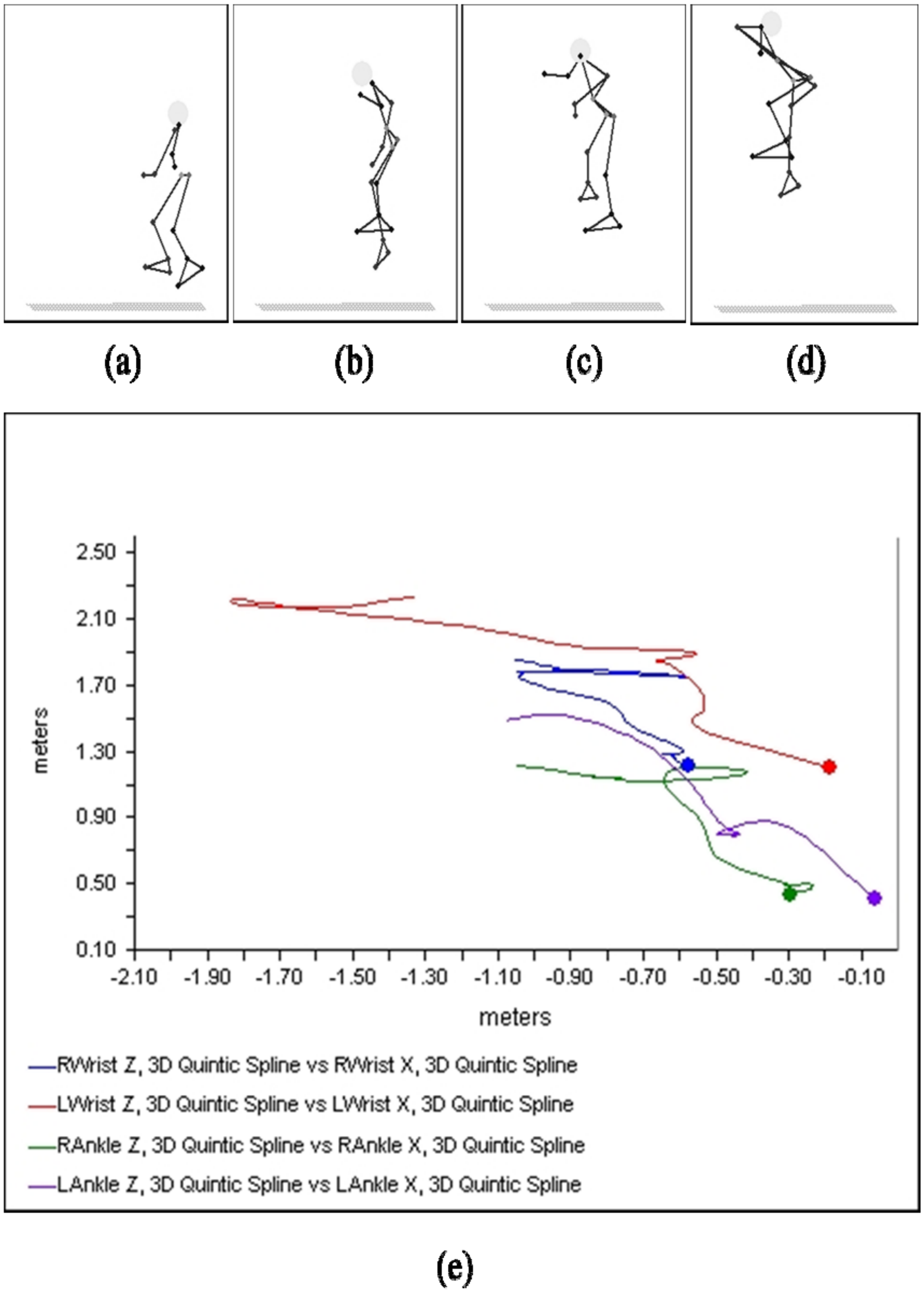


Figure 34: Steps in ingress of JD 8200 and ankle/wrist trajectories

4.7.2.2 Egress

Figure 35 shows the egress of a select participant on JD 8200. The Figures (a), (b), (c), and (d) show the stick figure of egress of the participant at different time points. Figure (e) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is dismounting the tractor.

4.7.3 MX 275

4.7.3.1 Ingress

Figure 36 shows the ingress of a select participant on MX 275. The Figures (a), (b), (c), and (d) show the stick figure of ingress of the participant at different time points. Figure (e) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is mounting the tractor.

4.7.3.2 Egress

Figure 37 shows the egress of a select participant on MX 275. The Figures (a), (b), (c), and (d) show the stick figure of egress of the participant at different time points. Figure (e) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is dismounting the tractor.

4.7.4 JD 8420

4.7.4.1 Ingress

Figure 38 shows the ingress of a select participant on JD 8420. The Figures (a), (b), (c), and (d) show the stick figure of ingress of the participant at different time points.

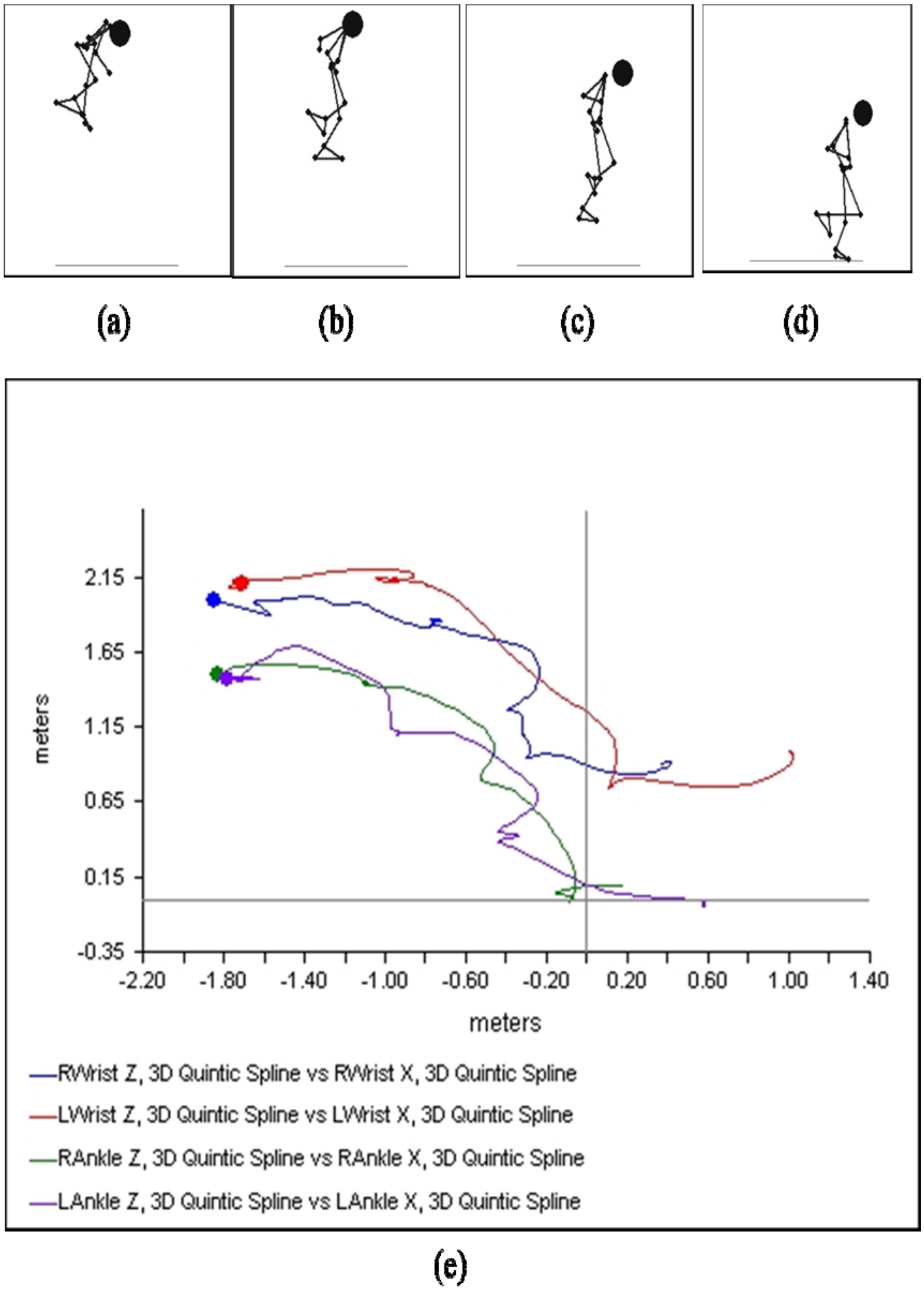


Figure 35: Steps in egress of JD 8200 and ankle/wrist trajectories

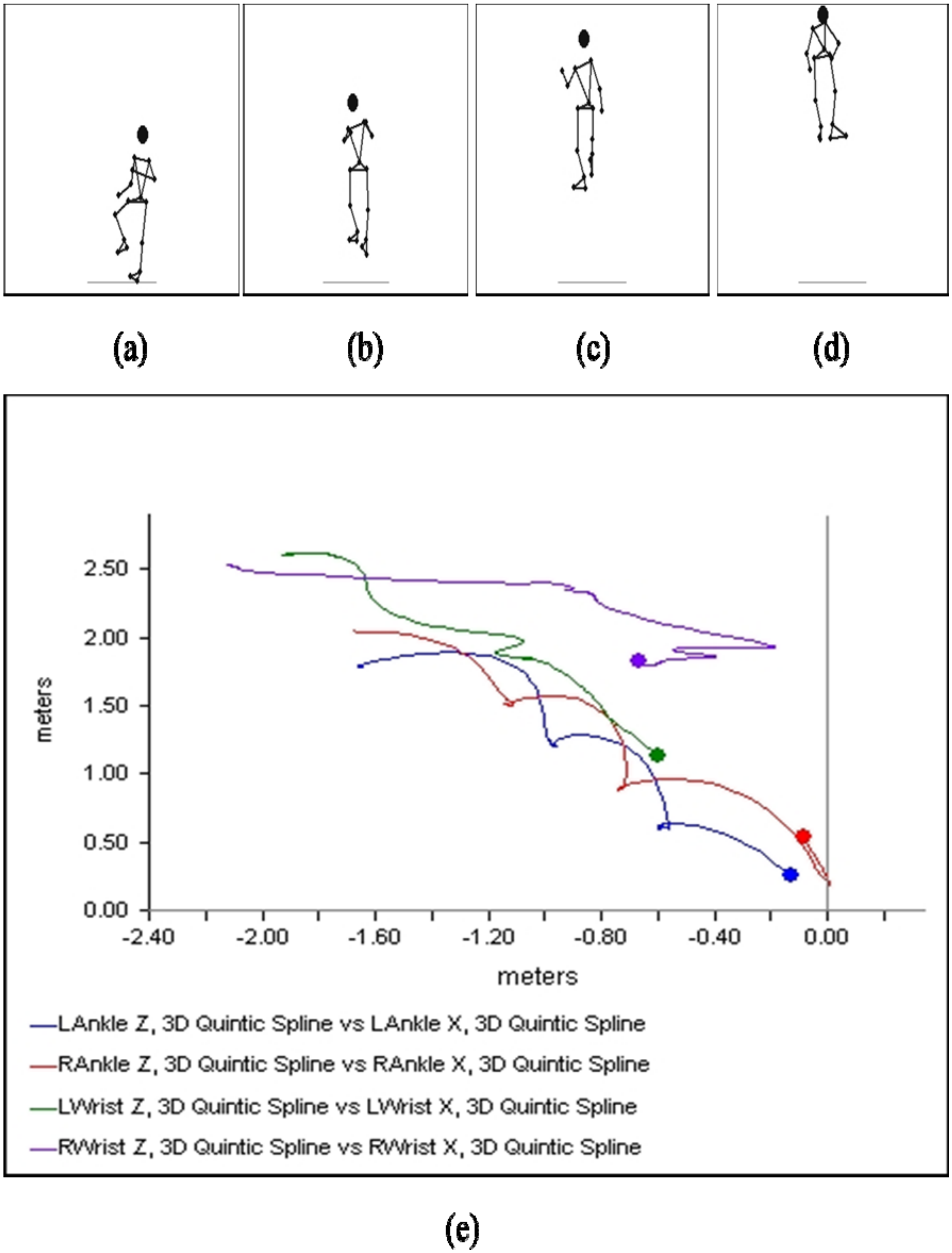
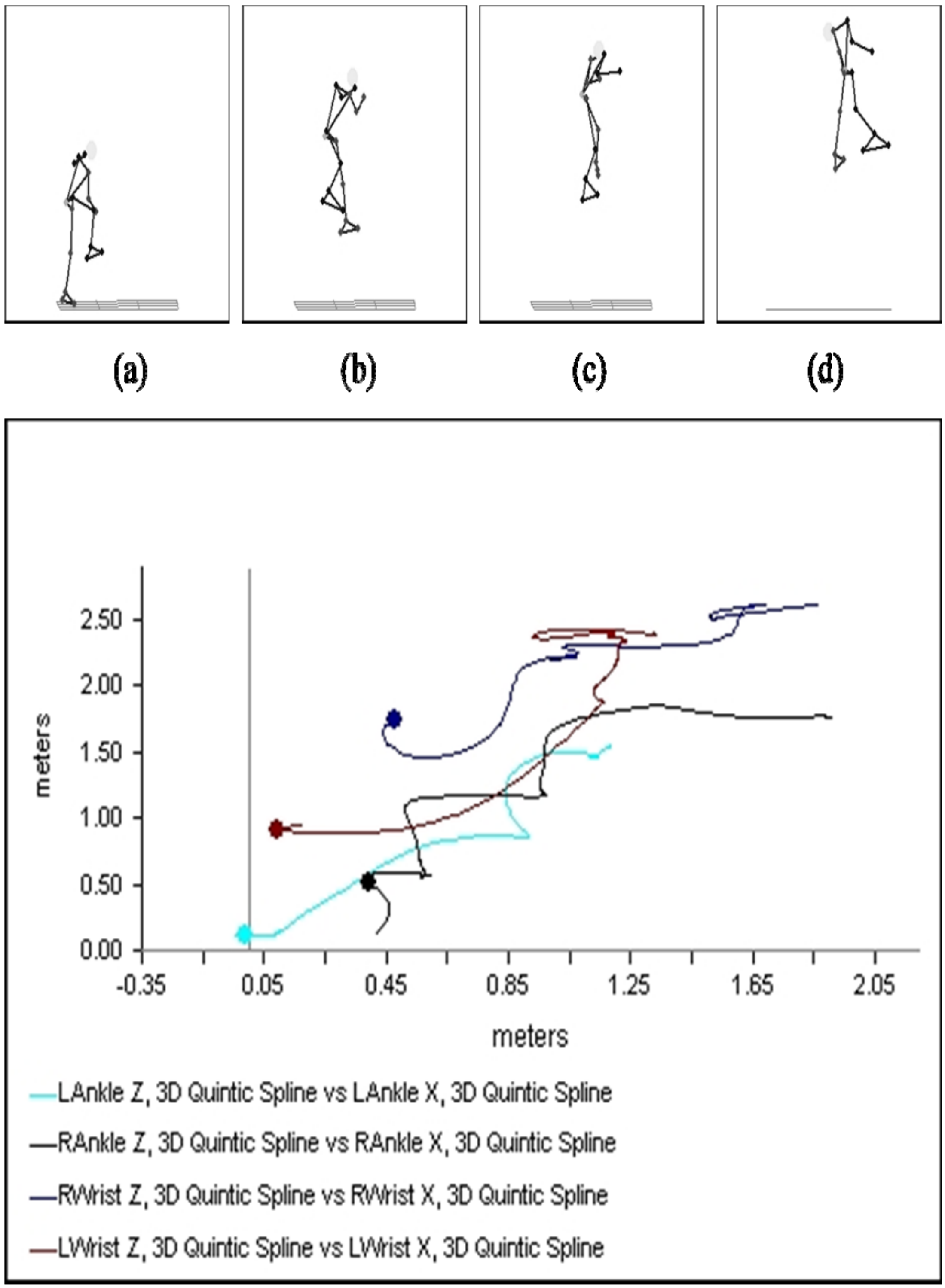


Figure 36: Steps in ingress of MX 275 and ankle/wrist trajectories



(e)

Figure 37: Steps in egress of MX 275 and ankle/wrist trajectories

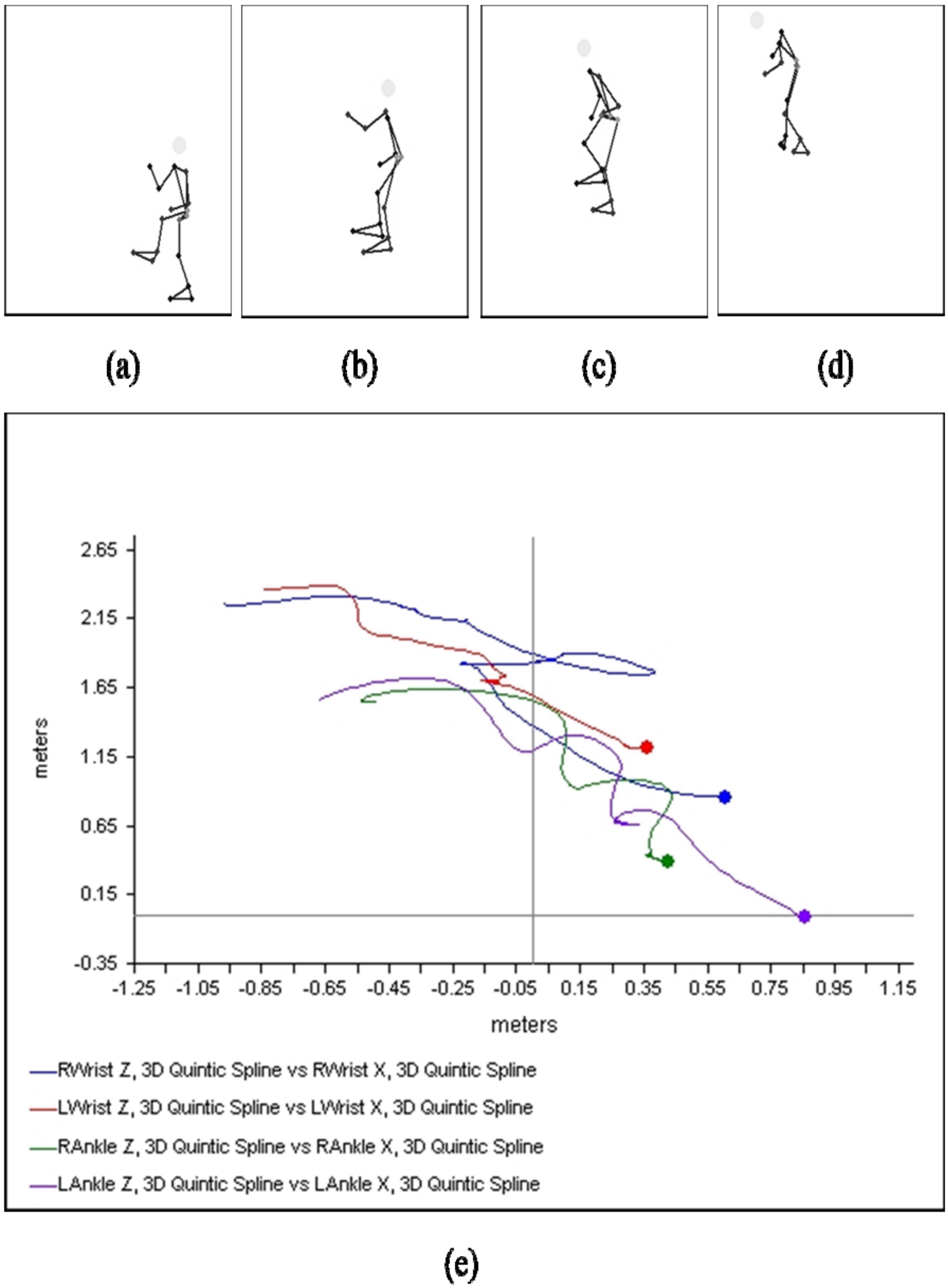


Figure 38: Steps in ingress of JD 8420 and ankle/wrist trajectories

Figure (e) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is mounting the tractor.

4.7.4.2 Egress

Figure 39 shows the egress of a select participant on JD 8420. The Figures (a), (b), (c), and (d) show the stick figure of egress of the participant at different time points. Figure (e) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is dismounting the tractor.

4.7.5 JD 9400T

4.7.5.1 Ingress

Figure 40 shows the ingress of the participant on the tractor model JD 9400T. The Figures (a), (b), (c), and (d) show the stick figure of ingress of the participant at different time points. Figure (e) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is mounting the tractor.

4.7.5.2 Egress

Figure 41 shows the egress of the participant on the tractor model JD 9400T. The Figures (a), (b), (c), and (d) show the stick figure of egress of the participant at different time points. Figure (e) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is dismounting the tractor.

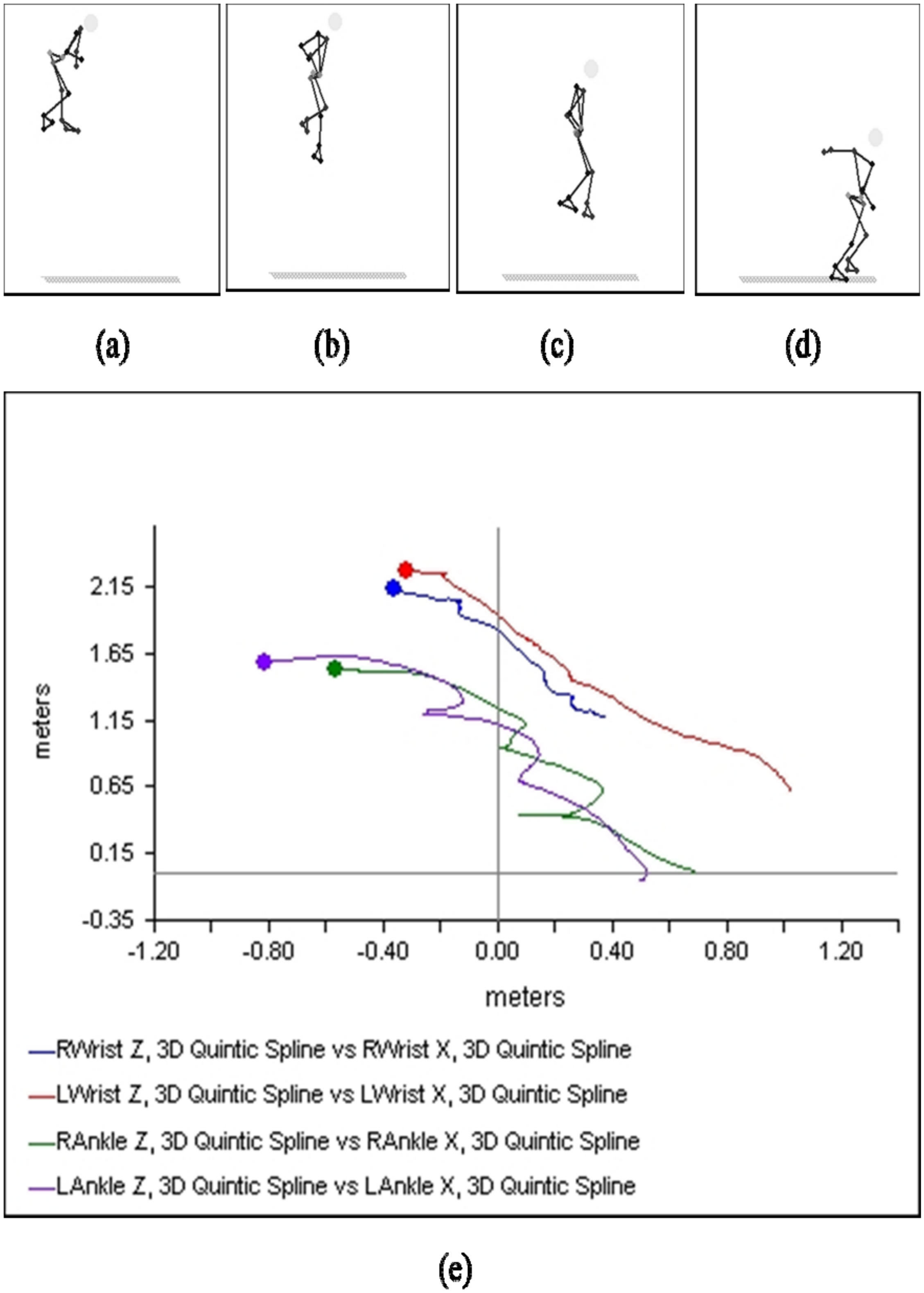


Figure 39: Steps in egress of JD 8420 and ankle/wrist trajectories

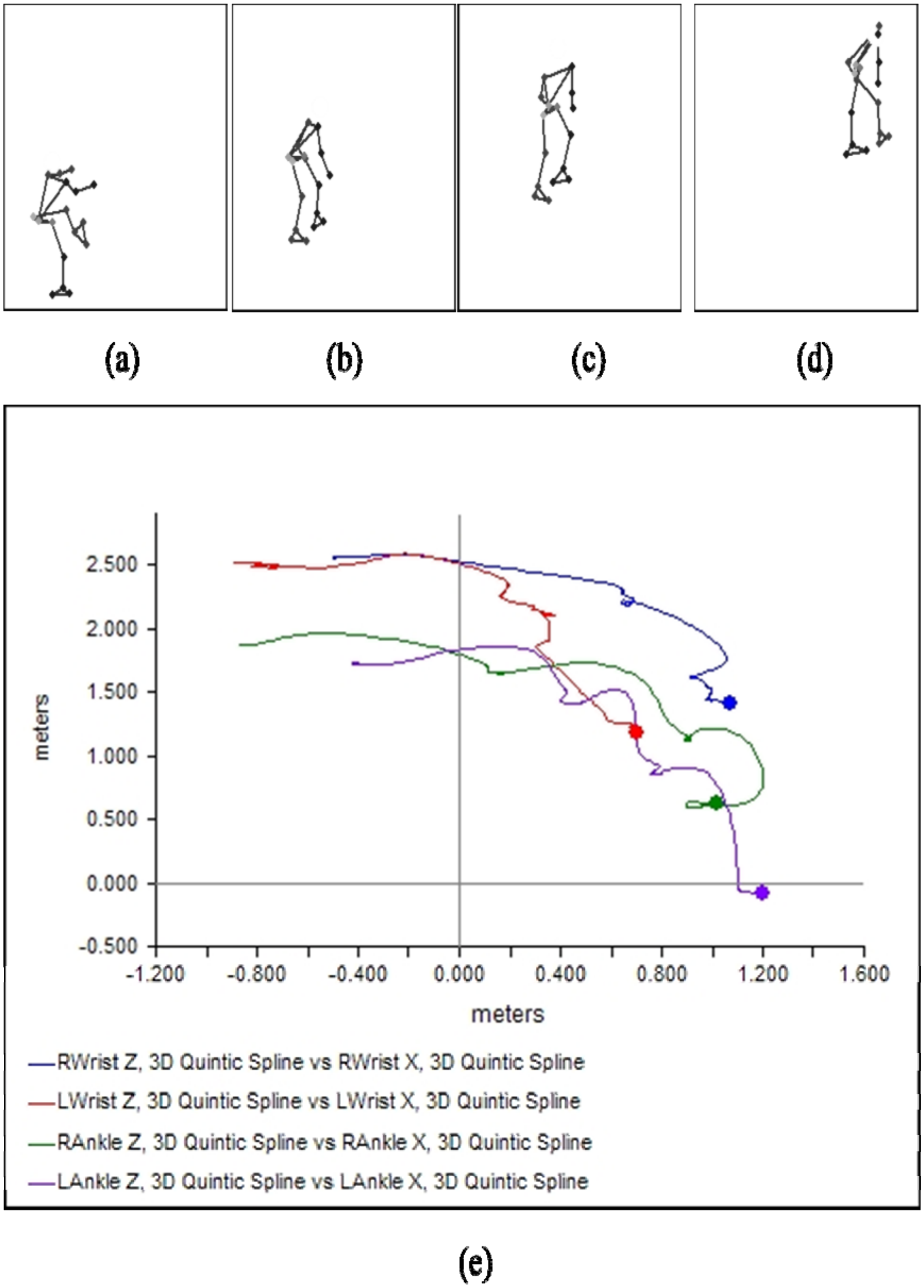
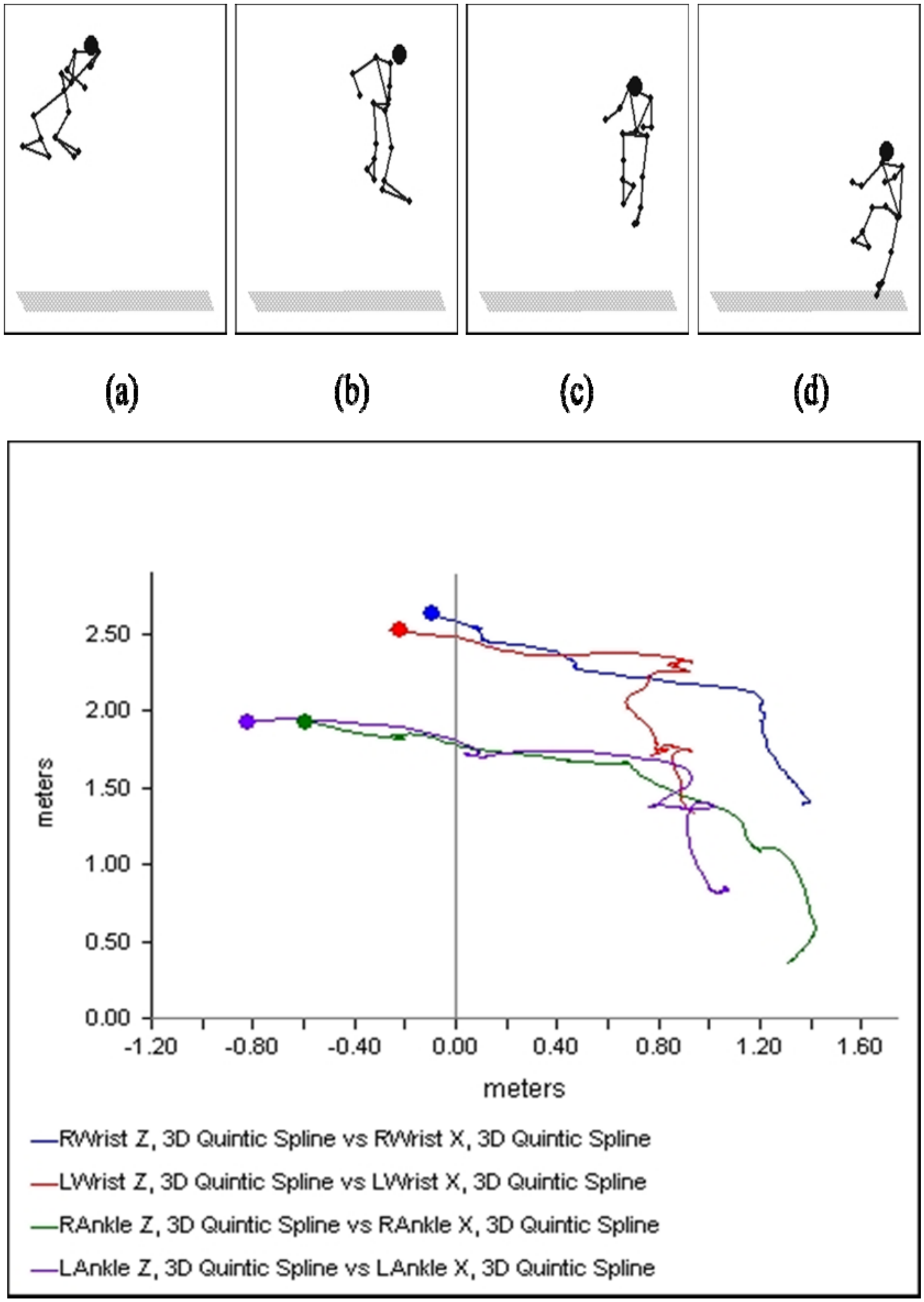


Figure 40: Steps in ingress of JD 9400T and ankle/wrist trajectories



(e)

Figure 41: Steps in egress of JD 9400T and ankle/wrist trajectories

4.7.6 FORD 4600

4.7.6.1 Ingress

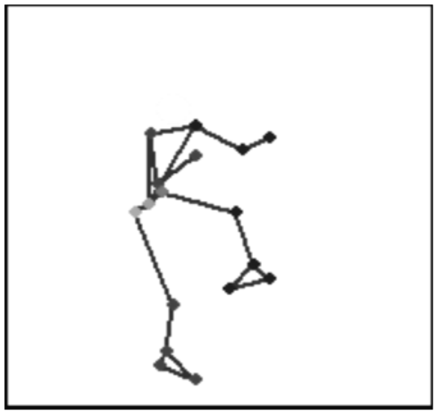
Figure 42 shows the ingress of the participant on the tractor model FORD 4600. The Figures (a) and (b) show the stick figure of ingress of the participant at different time points. Figure (c) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is mounting the tractor.

4.7.6.2 Egress

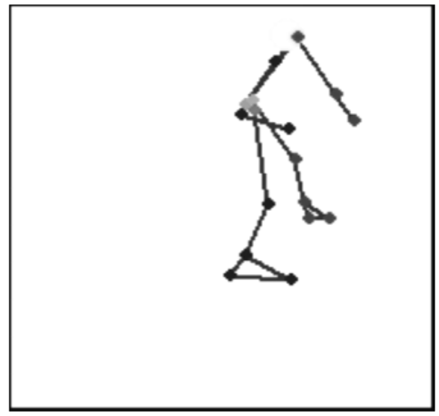
Figure 43 shows the egress of the participant on the tractor model FORD 4600. The Figures (a) and (b) show the stick figure of egress of the participant at different time points. Figure (c) focuses on the trajectories of the right and left ankle, and the right and left wrist while the participant is dismounting the tractor.

4.8 Discussions

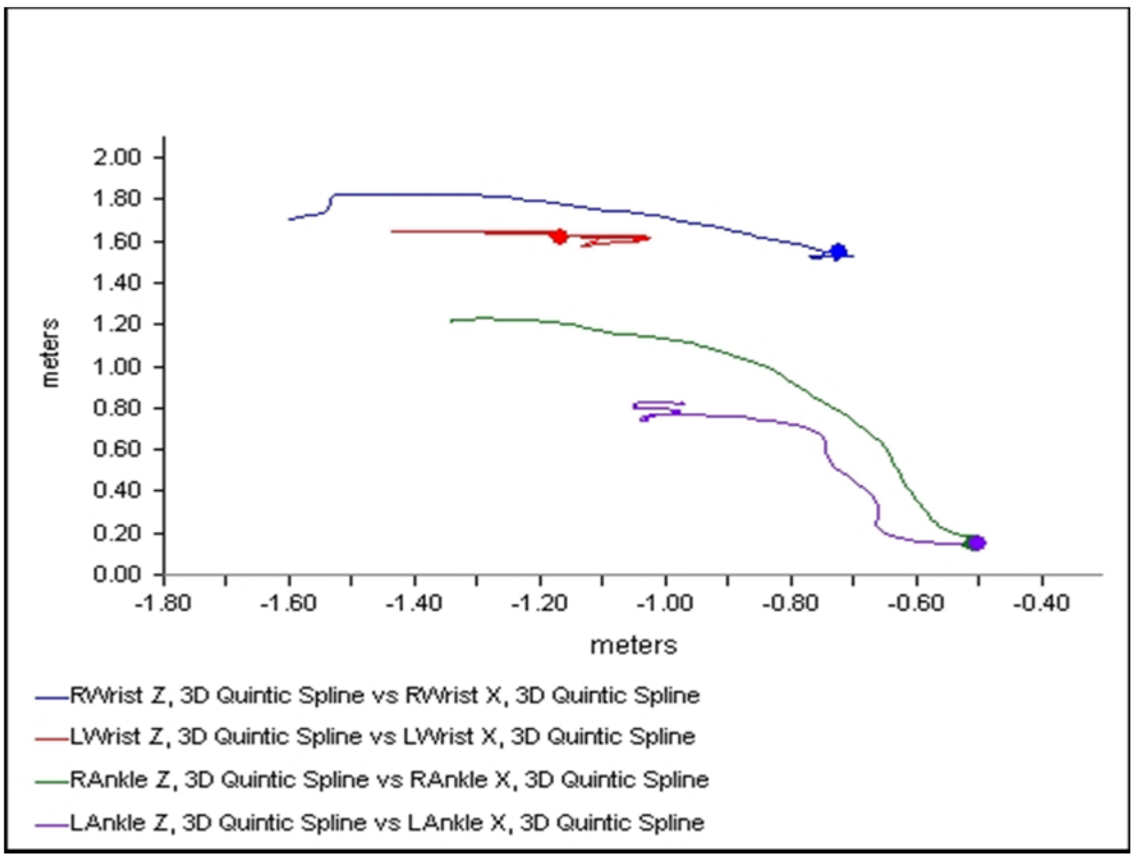
It was observed that the positions of the grab rails and steps were best served usually when the operators were mounting the tractor. All the operators appeared to have maintained the 3-point contact while mounting the tractor. Less attention has been paid in maintaining the 3-point contact while dismounting. It is believed that most slips or falls occur during the egress from the tractor. Also, most severe consequences like lower limb or back injuries result when dismounting the tractors. Some of the participants preferred to jump off the last step of the tractor to the ground. The possible future observations could be the impact of repeated jumps on the spinal column and other parts of the skeletal system. When a tractor operator lands on the ground, the legs absorb energy due to the



(a)

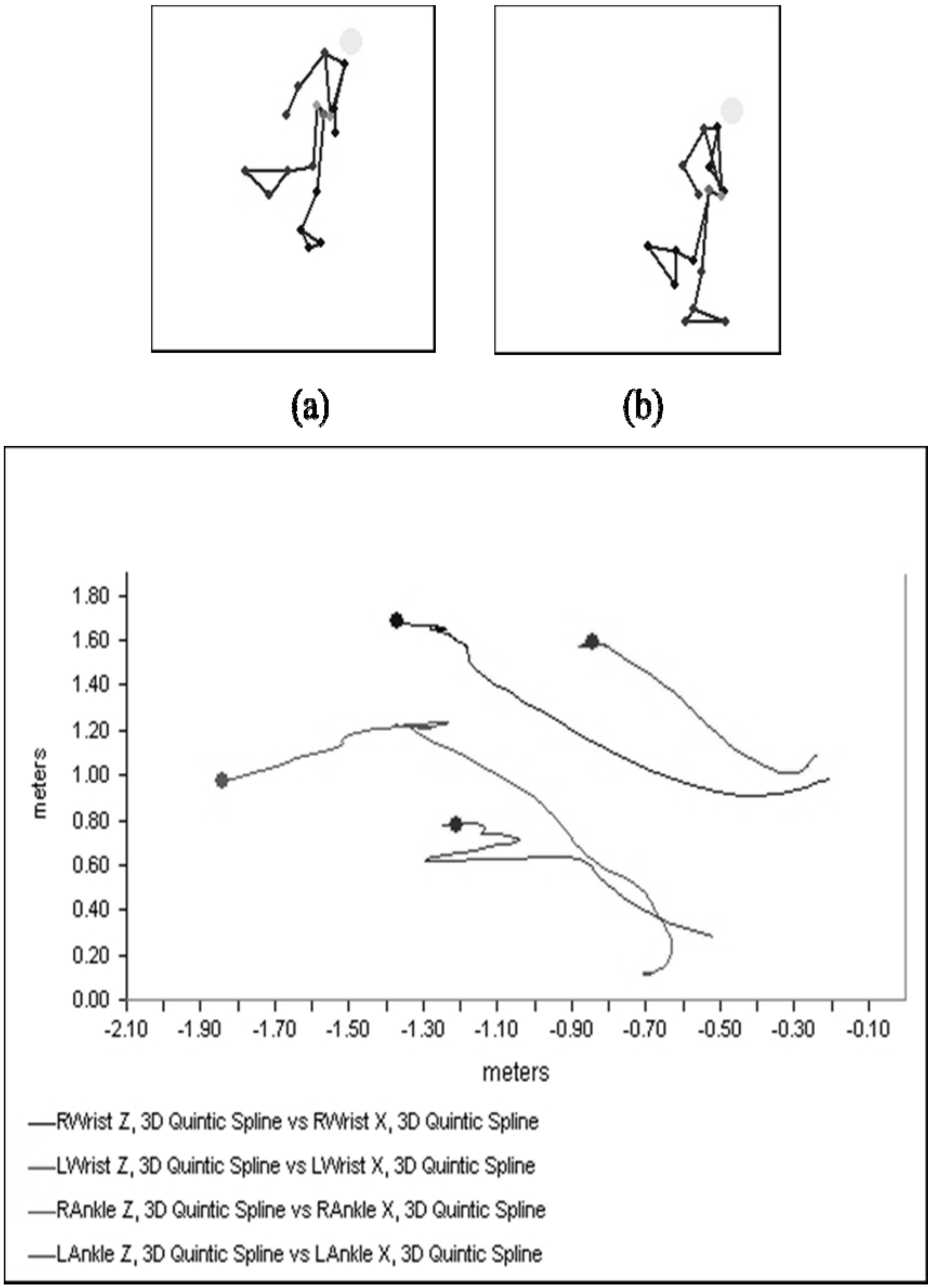


(b)



(c)

Figure 42: Steps in ingress of FORD 4600 and ankle/wrist trajectories



(c)

Figure 43: Steps in egress of FORD 4600 and ankle/wrist trajectories

impact, and the force is transmitted from the ground through the ankles, knees, hips, and back.

Data from the hand and foot trajectories while mounting and dismounting were reviewed to investigate changes in vertical and horiztonal displacement and velocity as a function of track mounting/dismounting technique, and tractor model. The risk of a slip-and-fall accident would be considered low when the calculated required friction coefficient is less than the ratio of horizontal (F_h) and vertical (F_v) force components applied to the steps and ground, as depicted in Figure 44. An estimate of the forces was derived from the relationship between the trajectory, number of points of contact, and accelerations components. Figure 45 illustrates this technique. Steeper trajectories representing a decrease in the ratio Fs/Fz would likely be safer and prevent slips. This is accomplished by a more stable center of mass located above the feet, and relies less on

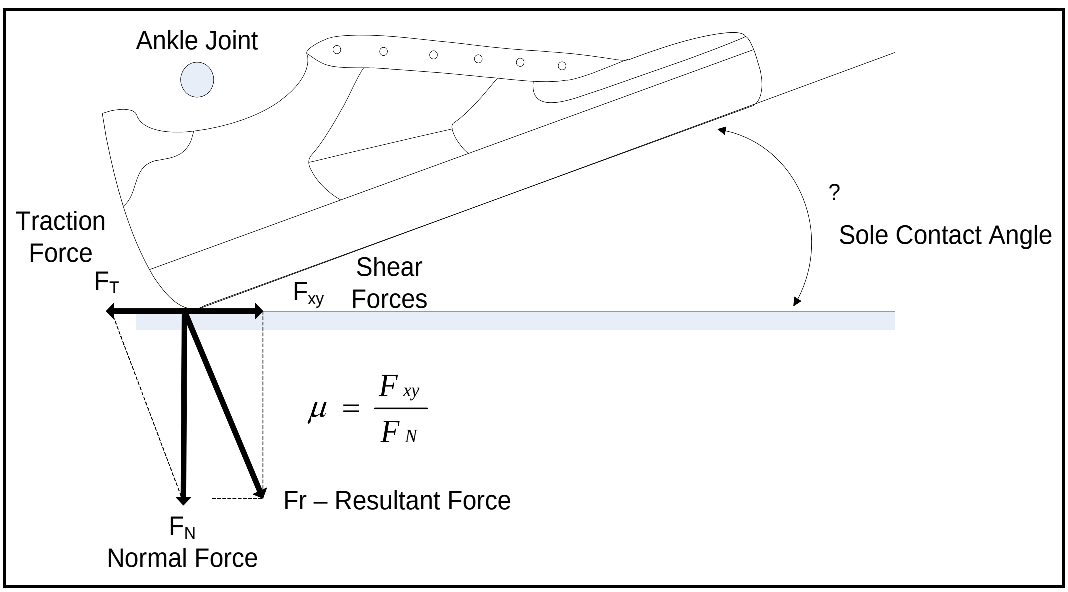


Figure 44: Foot contact diagram depicting the relationship between shear forces and normal force as a function of foot contact angle

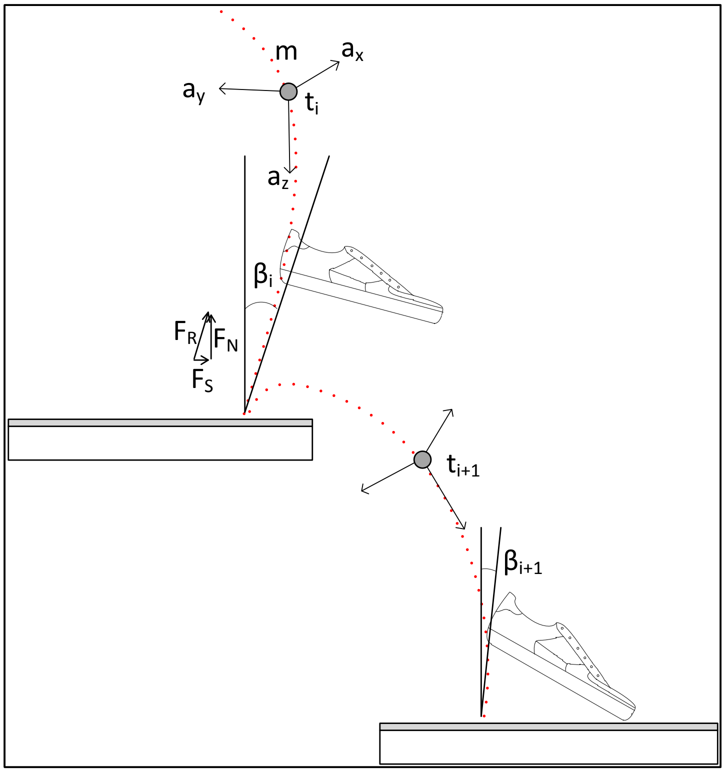


Figure 45: Foot trajectory over time while dismounting. The forces are estimated as a function of acceleration and estimated mass during dismount.

hand holds and arm strength to support the body in the event of traction loss. Further investigation of this technique is warranted to describe its utility and the relationship between hand and foot trajectories and required friction to prevent slipping. As the position and angle of contact changes as a function of dismounting technique and tractor design, the required coefficient of friction to avoid slipping would also change. Further investiation of this relationship should be pursued in future work.

More attention should be paid when dismounting from the last step of the tractor. Also, most of the operators seemed to have preferred facing away from the cab while dismounting. In such cases, the operator may not be able to see the steps or maintain 3-point contact due to the difficulty in grasping grab rails. Hence some of the operators had to take support of the cabin door while getting down. Keeping these points in mind, some design recommendations have been provided.

4.9 Recommendations for Design Guidelines

Research indicated that the greatest over-all improvement in safety would be achieved by making the following changes to ingress/egress system of the tractors (David Johnson 1980).

1. Redesign the lower portion of existing steps to reduce movement during usage, and to reduce the distance between the ground level and the first step.
2. Modify the ingress/egress systems to bring them into conformity with the preferred values of the SAE J-185 design recommendations.
3. Designs conforming to the SAE J-185 with an angle of inclination greater than 60^0 require the use of both hands for safe use. Proper handrails must be provided.

5 CONCLUSIONS

This study focused on finding out the factors that could have an influence on the slips and falls of tractor operators while mounting and dismounting the cab. Results from the survey described additional factors related to ergonomics and human factors, including seat comfort, control layout, and musculoskeletal discomfort. After testing whether the age of the tractor operator or the duration of time on the tractor had any influence on self-reported pain of different body parts, it was found that there is a significant association on some body parts such as neck, upper arm, lower back, and upper back. Also, operators who reported having tractor seats with insufficient degrees of freedom for rotation reported greater neck pain. Additionally, summer is the season when the maximum number of falls was reported. Furthermore, John Deere was the model of the tractor most frequently used by these farmers, followed by Case and Massey Ferguson. Additionally, a field study was conducted with 15 operators and 5 tractors, the tractors were compared to the SAE J-185 standards. It was found that JD 8200 conformed well to the limits and standards. Also, it was observed that all the subjects faced the cab while mounting the tractor, while most of the subjects failed to maintain a 3-point contact while dismounting. Using the motion analysis system ViconMotus, the wrist and ankle trajectories of the subjects mounting and dismounting each tractor were recorded. Since the sample size is small, these results cannot be generalized to a greater population, but there appears to be an association with technique and tractor model and a risk of falls.

Future work should include biomechanics studies to evaluate mounting and dismounting technique related to acute injuries including falls.

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